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FUTURE SEA LEVEL RISE IMPACTS MARYLAND'S ATLANTIC COASTAL BAYS

Prepared by

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Maryland Department of Natural Resources
Coastal and Watershed Resources Division
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INTRODUCTION

I. PROJECT OBJECTIVES

Maryland's Atlantic coastal bays are valuable because of their coastal location which attracts development, and because they support abundant natural resources, including tidal wetlands. Accelerated sea-level rise projected for the next century will have severe impacts on both development and natural resources. In order to responsibly manage land use in this region, the impact of sea level rise must be addressed. This study has three major aims:

(1) Predict future wetland and upland losses around the northern portion of Maryland's Atlantic coast bays (namely Assawoman Bay, and Isle of Wight Bay) to the years 2020, 2050 and 2100 for eight realistic scenarios of sea-level rise: 0.4 ft and 0.5 ft (2020), 0.8 ft and 1.5 ft (2050) and 1.4 ft, 1.7 ft, 3 ft and 4.4 ft (2100);

(2) Analyze the impacts of the land losses predicted by each sea-level rise scenario with respect to present development patterns and likely future development, including net wetland losses, real estate upland losses and enhanced risk of flooding; and

(3) Examine and develop strategies that would be useful at the state and local level to mitigate these impacts such as retreat, accommodation, and protection.

II. GLOBAL WARMING AND SEA-LEVEL RISE

It has long been theorized that an increase in atmospheric concentrations of carbon dioxide, primarily due to fossil fuel combustion, would cause a gradual rise in global temperatures. The amount of carbon dioxide (CO_2) in the atmosphere, now 340 parts per million (ppm), has ranged from several thousand to as low as 200 ppm. These changes, however, have occurred on geological time scales (over thousands and millions of years) and have been primarily due to natural phenomenon. Now CO_2 and other trace gases (methane, nitrous oxide, and chlorofluorocarbons) are accumulating in the atmosphere at an unprecedented rate with effects that will be measured in decades. Atmospheric measurements show that concentrations of CO_2 have increased 20 percent since 1960 and are continuing to rise (Shands and Wells, 1987).

While it is still being debated if global warming has begun, it is clear that sea level has been rising as indicated by tide gauge data from around the world's coasts, including those in Maryland (Douglas, 1991). Although some government officials, scientists and the general public are unaware of or have largely ignored these warnings, the evidence for global change and its impacts is mounting. The relevant facts include the following:

1. The concentrations of carbon dioxide and other greenhouse gases are rapidly increasing in the atmosphere. The amount of CO_2 in the atmosphere is now more than 340 ppm (Shands and Wells, 1987).

2. World temperatures are rising (about 0.5°C in the last 100 years). The 1980's was the warmest decade on record (IPCC, 1990a).

3. Regardless of future emission policy, further global warming is inevitable due to the greenhouse gasses already emitted (i.e. there is a "commitment" to global warming).

4. Water expands when heated; thermal expansion of near surface ocean waters as well as melting of land-based glacial ice will increase sea level.

5. Most mid-latitude glaciers have retreated during the 20th century (releasing their ice-locked water to the ocean) (IPPC, 1990a).

6. Relative sea levels have risen at most tide gauges in the last century; the eustatic (worldwide) contribution is estimated to be about 0.18 m during the last century (Douglas, 1991).

7. Sea-level rise and shoreline recession are directly linked as shown by laboratory experiments and erosion in the Great Lakes region during periods of high water levels (Bruun, 1962; Hands, 1983).

8. Shorelines are retreating on a global basis; approximately 70% of the sandy beaches worldwide are presently eroding (Bird, 1985). In the U.S. best estimates are that 90% of sandy beaches are eroding (Leatherman, 1988).

9. Coastal wetlands are lost when sea-level rise exceeds sedimentation rates; Louisiana is losing about 130 square kilometers of wetlands annually (DeLaune, et al., 1983). Wetland loss in Louisiana largely due to land subsidence but provides an example of the fate of other coastal wetlands in response to accelerated sea level rise.

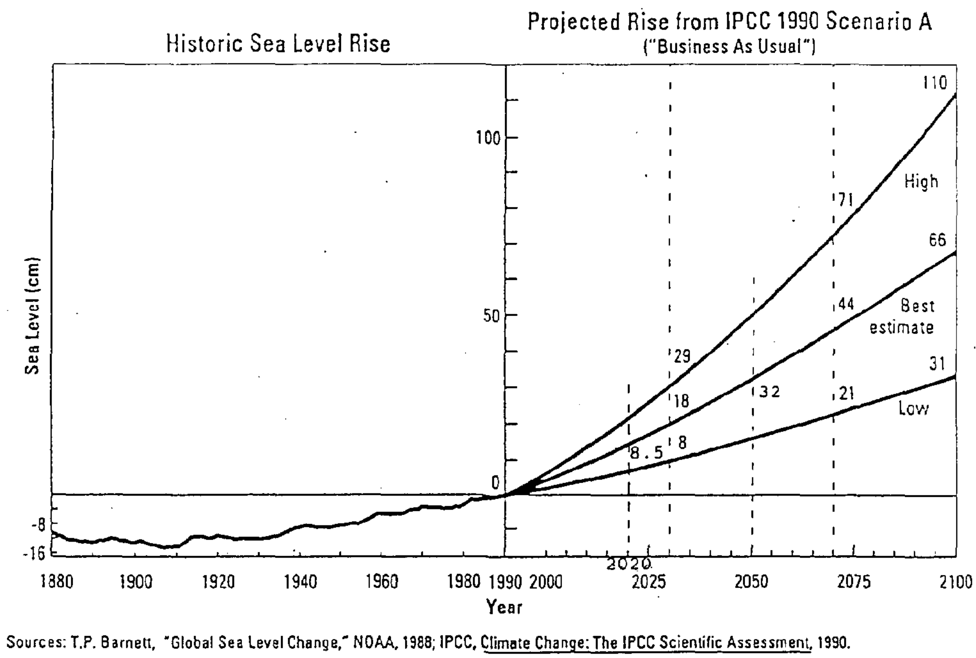
10. Global warming will most likely increase the intensity of hurricanes (Emanuel, 1987), which have the greatest impact on low-lying coastal landforms and the area's inhabitants by inducing massive erosion and flooding.

11. There is a worldwide trend of coastal urbanization at more than twice the inland rate (NOAA, 1990). These coastal areas contain a disproportionate share of the nation's economic wealth. In addition, beach front property is some of the most expensive real estate in the U.S. (Leatherman, 1988).

12. Sea-level is predicted to rise worldwide by as much as 1.10 meters by the year 2100 (Figure 1); best estimates are for a 0.66 meter rise with at least a 0.31 meter global or eustatic increase within the next century (IPCC, 1990a).

13. Global environmental problems are intensified in the coastal zone; sea-level rise is pushing the shore landward at the same time that population growth and coastal urbanization are rapidly increasing (Figure 2).

Of all the potential impacts of human-induced climate change, a global rise in sea level appears to be the most certain. Over the next few decades we can anticipate that sea-level will continue to rise at a rate similar to or slightly exceeding the recent experience. By the middle of the next century, sea level can be expected to rise by a factor of 2 to 3, and it may ultimately rise 1.10 meters during the next 100 years (Figure 1).



Sources: T.P. Barnett, "Global Sea Level Change," NOAA, 1988; IPCC, Climate Change: The IPCC Scientific Assessment, 1990.

Figure 1. Sea-level rise scenarios.

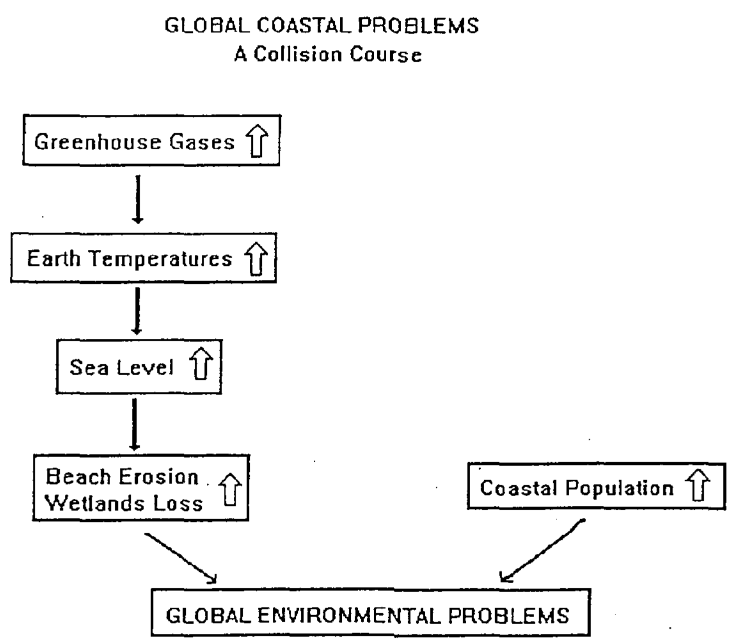


Figure 2. Global Coastal Problems: A Collision Course

III. IMPACTS OF SEA-LEVEL RISE

Scientists commonly cite five physical impacts due to sea level rise (Leatherman, 1983):

(1) beach and upland erosion;
(2) inundation of low-lying lands and wetlands;
(3) salt-water intrusion into aquifers and surface waters;
(4) higher water tables; and
(5) increased flooding and storm damage.

Erosion and inundation in the coastal zone are accelerated by higher water levels, the impact of which will be accentuated in the future if low-lying areas are developed. Sea-level rise would increase the severity of storm-related flooding. The higher base for storm surges would be an additional threat in regions where hurricanes are common. Higher water levels in the low-lying coastal zone may reduce drainage of adjacent land areas, which could damage roads, buildings and agricultural land. Salt-water intrusion into fresh water aquifers would contaminate drinking water. Wetlands are particularly at risk from sea level rise because they are directly dependent on water levels.

IV. SEA LEVEL RISE SCENARIOS

The relative sea level rise scenarios used in this analysis were obtained by adding the two components that are responsible for relative sea level change at any one coastline. These two components are:

(i) global or eustatic sea-level change; and
(ii) vertical land movement.

Eustatic sea-level change values for the years 2020, 2050 and 2100 were obtained from predictions made by the Intergovernmental Panel on Climate Change Working Group I (1990a; Figure 1). The IPCC predictions assume an acceleration of the rate of sea level rise based on predictions of global warming due to the "greenhouse effect." For the years 2020 and 2050 we examined only two scenarios of eustatic sea level: (1) Present Trend (no acceleration in eustatic sea level) and (2) Most Likely Trend in sea level (values obtained from the best estimate curve of Figure 1, middle curve). For the year 2100, we used the three IPCC sea level rise scenarios (Low, Best, and High) plus the present sea level trend (no acceleration). Thus, a total of eight scenarios were investigated.

Land subsidence values for the study area were obtained by subtracting eustatic sea level rise from relative sea level rise. This latter value was obtained from tide gauge data at Lewes, Delaware --the nearest long-term record (Lyles, Hickman and Debaugh, 1988). The tide gauge data indicate a relative rise in sea level of 0.39

m (1.3 ft) per century from 1919 to 1986. Eustatic sea level rise for the same period was estimated at 0.18 m (0.6 ft) (Douglas, 1990). Hence, the subsidence component is 0.21 m (0.68 ft) per century, or 0.23 m (0.7 ft) by the year 2100.

These two components were then added to determine the total relative sea level rise at the study area. The following table (Table 1) presents these sea level rise scenarios that will be used in this study (the base year is 1989):

Table 1. Sea Level Rise Scenarios for Study Area.

Year Scenario	Eustatic (feet)	Subsidence (feet)	Total Sea Level Rise (feet)
2020			
Present Trend	0.18	0.22	**0.4**
Best Estimate	0.28	0.22	**0.5**
2050			
Present Trend	0.37	0.43	**0.8**
Best Estimate	1.05	0.43	**1.5**
2100			
Present Trend	0.67	0.7	**1.4**
Low	1.02	0.7	**1.7**
Best Estimate	2.17	0.7	**3**
High	3.7	0.7	**4.4**

CHAPTER TWO
MARYLAND'S ATLANTIC COASTAL BAYS

Maryland's Atlantic coastal bays are a significant resource to the people of the state (see figure 3, pg 9). They present a microcosm of the global pressures on the coastal zone already described (Figure 2). Coastal land loss in this region is already a major issue as more and more people move closer to the water's edge. Rapid coastal changes are taking place, for instance at northern Assateague Island the shore is moving landward at an average rate of -9.1 meters/year. The island is likely to be breached near the Ocean City Airport before the year 2020 exposing the mainland shore to the Atlantic waves (Leatherman et al., 1987).

As the shoreline changes, it is projected that by the year 2100, the coastal population of Maryland will have increased by more than 66 percent above 1960 levels (NOAA, 1990). Development pressures in the coastal bays are increasing because Ocean City has approached saturation and as a result new shore front property has become scarce. This makes the relatively undeveloped coastal bays increasingly attractive for development (Maryland's Forgotten Bays, 1990).

The problems of the Atlantic coastal bays, especially development pressures, have been brought to the forefront by a recent conference held at Ocean City (Maryland's Forgotten Bays, 1990). A number of issues of relevance to this study were identified:

- Local land use plans need to recognize the impacts of sea-level rise and help to protect the resources of the coastal bays;

- The Chesapeake Bay Critical Area Program places setbacks and restrictions on development along the Chesapeake Bay and its tributaries, but there are no state or county laws or regulations requiring setbacks on the coastal bays;

- Present development proposals frequently do not take into account future coastal recession. The proposed marina at Ocean City Airport, opposite the point where Assateague Island is likely to breach, illustrates that some coastal developers are either not aware of or are unconcerned with scientific predictions;

- Wetland and other habitat losses would greatly reduce the commercial fisheries and ecological value of the bays; and

- Considerable local concern about these issues exists (e.g.; Baltimore Sun, May 14/15, 1990).

I. PHYSICAL CHARACTERISTICS

The study area is located on the northeastern corner of Worcester County, Maryland. It includes the outer bays lying between the mainland of Worcester County and the barrier island of Fenwick (Ocean City). The study area shoreline extends about 41 miles from just south of Route 50 (before it crosses to Ocean City) to the area of Back Creek on Assawoman Bay just south of the border between Maryland and Delaware (Figure 3). The study area consists of a series of "necks" (Sinepuxent, Turville, Jenkins, and St. Martin) separated by creeks (Turville, Manklin and St. Martin River).

A recent morphological study (Demarest and Leatherman, 1985) determined that the present mainland shores of the Delmarva Peninsula, including the study area, developed over the last million years. These researchers found three ancient barrier islands in the study area that were dated to the Pleistocene. These barrier islands are located sub-parallel to the present shore and are referred to as the Bethany, Cedar Neck and White Neck barriers, dated at 0.06, 0.6 and 1.0 million years respectively (Figure 4). The pre-existing topography plays an important role in the morphologic development of these coastal areas. For example, the steep slopes on some parts of the study area can be traced back to the Pleistocene shoreface (scarp) of the ancient barriers.

The topography of the study area is relatively low, not exceeding 10 feet. The bays shorelines are generally gentle compared to that of the banks of the creeks. A typical cross-section of the shores show the presence of a scarp between the 1 and 3 feet contour lines, while for contours higher than 4 feet the slopes become gentler (see fig 16 on pg 50).

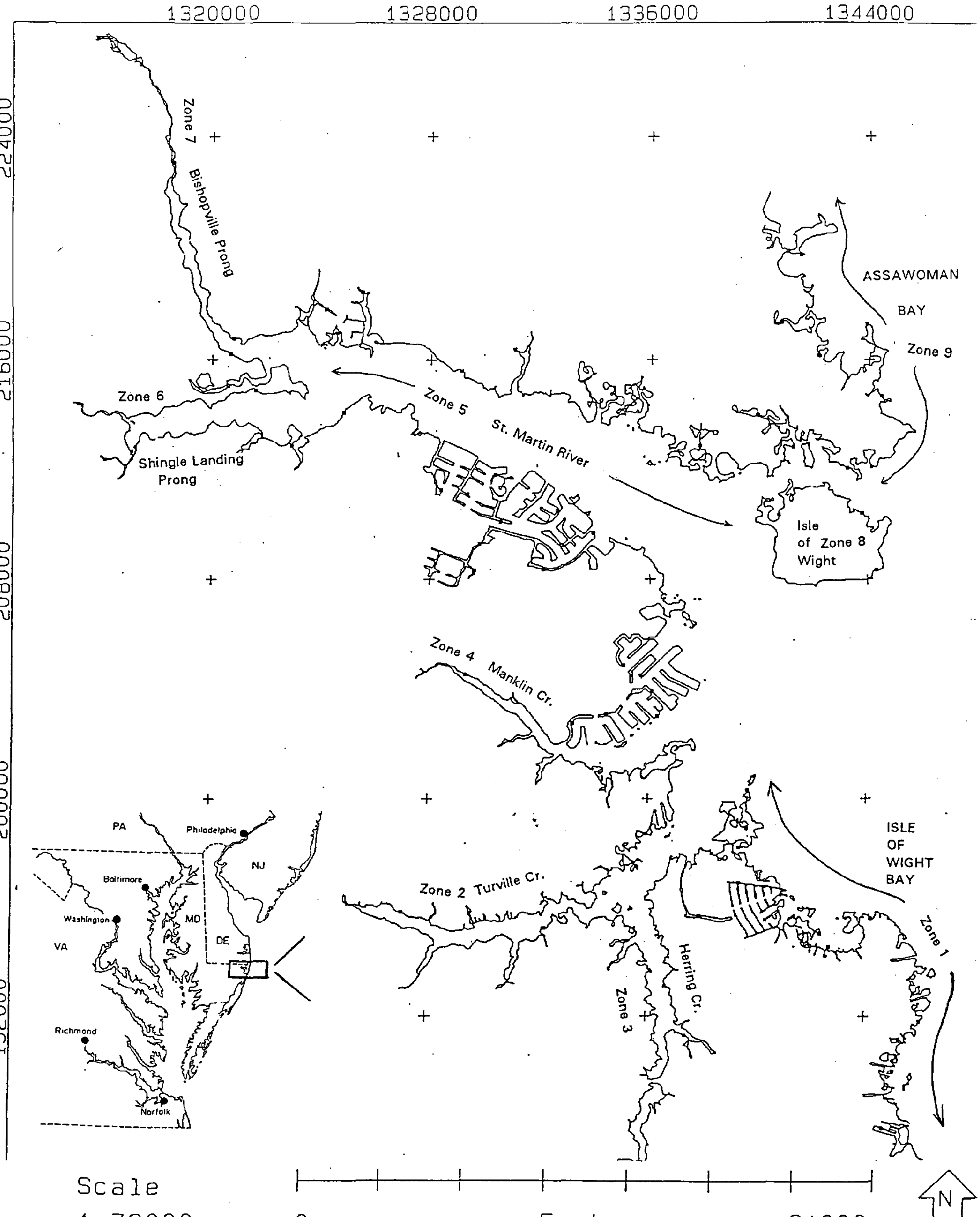


Figure 3. Study area and zonation

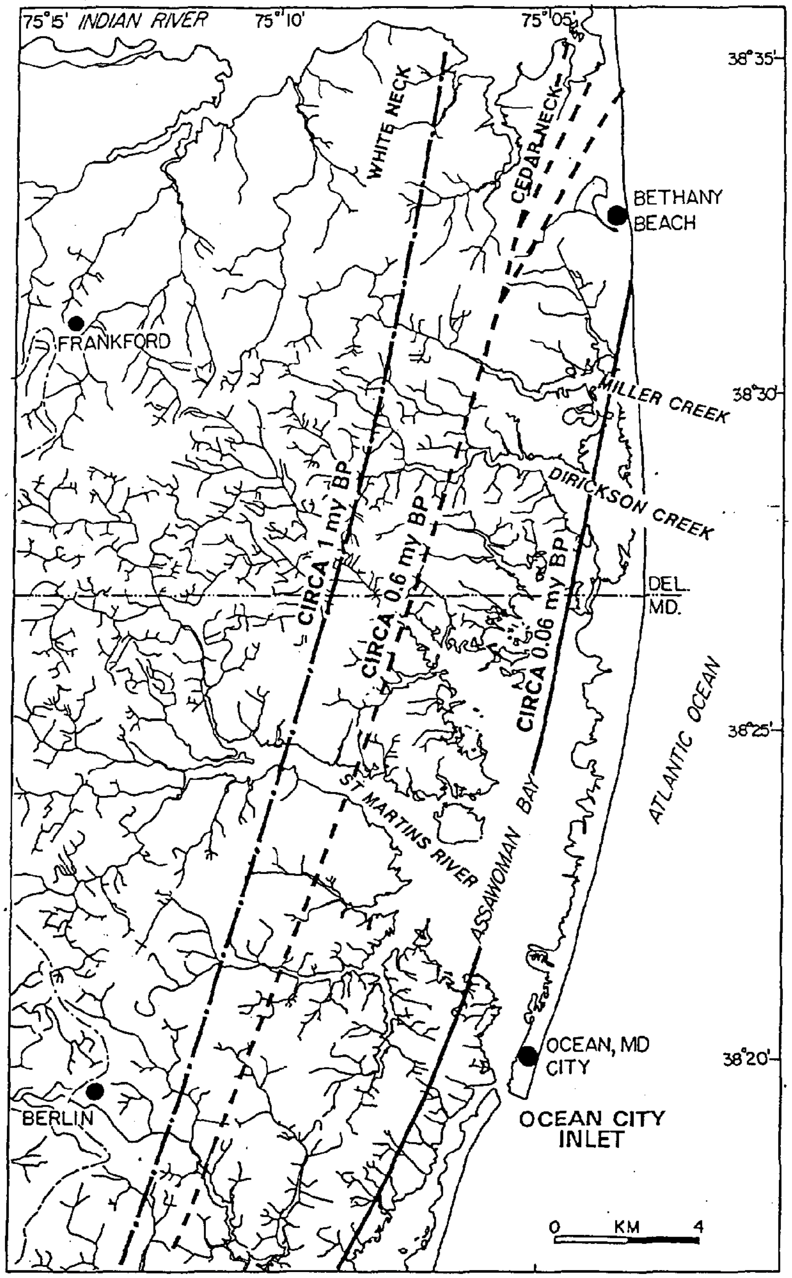


Figure 4. Ancient barriers in the study area (Demarest and Leatherman, 1985)

According to 1989 aerial photography, about 58 percent or 24 miles of the entire shoreline of the study area (41 miles) contain wetlands. The width of these wetlands vary along the shoreline, from a minimum of 40 feet (on the Turville Creek) to a maximum of about 1000 feet (Assawoman Bay). The most extensive wetlands occur on the north bank of the St. Martin River and the shores of the Assawoman Bay. It was estimated that presently wetlands cover about 1500 acres in the study area. Most of these wetlands have suffered extensive erosion (Figures 5 and 6) and drowning since 1850.

Coastal wetlands are subject to flooding by brackish or salty water and are composed of salt-tolerant plants. Because of the changing relative influence of various governing factors, such as tidal range and slope, there is a gradation in plant species from the lowest elevation of the wetlands to the upper boundary. Generally, one can easily distinguish between the lower wetlands (vegetated tidelands) and the upper wetlands (Figure 7).

It has been recognized that coastal wetlands are vital areas because they play a valuable and critical role in the functioning of coastal ecosystems. The benefits of wetlands are: habitat for many important estuarine species, shore stabilization, flood control, water purification and recreation (Clark, 1983). Wetland vegetation plays an important role in converting inorganic compounds (nutrients) and sunlight into stored energy. When the dead leaves and stems of the wetland plants enter the water and are broken down by bacteria, they are transformed into small particles of organic detritus, which is food for fiddler crabs, worms, snails, mussels and the myriads of larval stages of fish and shellfish of estuarine waters. This rich environment provides food and habitat necessary for the protection and survival of various species; many of which are commercially important.

Wetland vegetation also removes toxic materials and excess nutrients from estuarine waters. In addition, sediment and other inert suspended materials are mechanically and chemically removed from the water and deposited in the marsh, reducing the sedimentation of navigation channels and shellfish beds. Wetlands serve not only to stabilize the shoreline and prevent erosion but actually can extend the land's edge by trapping sediments and building seaward.

Wetlands provide storm protection for urbanized areas in several ways. The marshes create surface friction for both tidal surges and winds. The result is that marshes help reduce tidal surge levels and wind velocities of storms. Wetlands have also recreational value as they are used for fishing, hunting, photography, and boating.

Figure 5. Erosion at the edge of the marsh

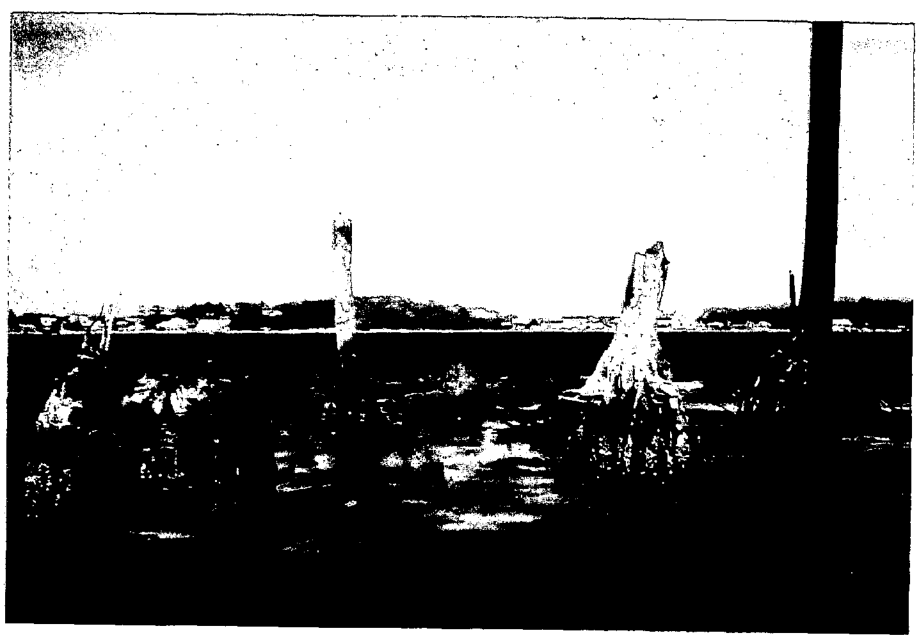


Figure 6. Inundation of marsh has caused upland vegetation to die

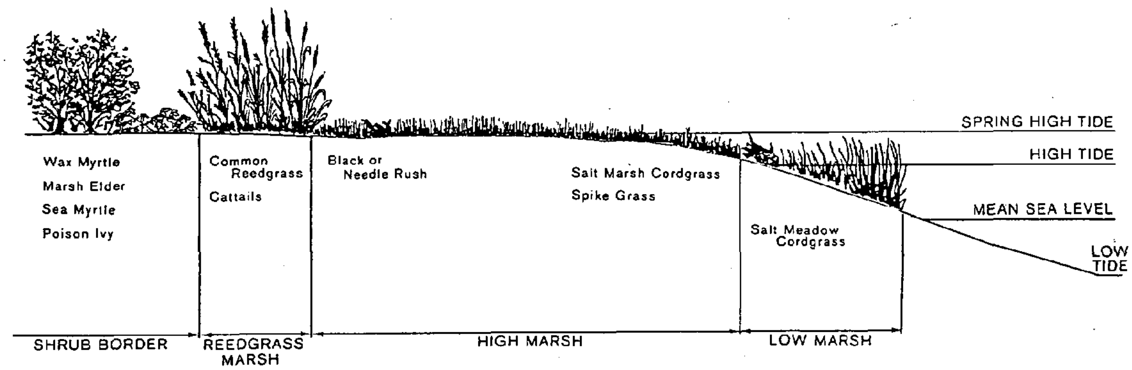


Figure 7. Salt marsh zonation (from Leatherman, 1988)

II. DESCRIPTION OF ZONES

In order to easily describe the study area it was divided into 9 zones according to the type of environment and geography (Figure 3). Zone 1 encompasses 4.66 miles of the study area and includes the shores of the Isle of Wight Bay from Route 50 north to Keyser Point. Urban developments such as West Ocean City, Bay Shores Acres, Captain Hills and Cape Isle of Wight are located in this zone. Zone 2 encircles the banks of Turville Creek, a tributary of Isle of Wight Bay and is about 8.63 miles. Herrings Creek, a tributary of Turville Creek, is Zone 3 with a shoreline length of about 4.5 miles (Figure 8). The banks of Manklin Creek, about 4.75 miles, is Zone 4, a tributary of Isle of Wight Bay, including the development Ocean Pines. Zone 5 encompasses the banks of Saint Martin River, about 7.17 miles (Figure 9). The banks of Shingle Landing Prong (3.52 miles) and Bishopville Prong (2.66 miles) are part of the St. Martin river system and are Zone 6 and 7, respectively. The Isle of Wight was assigned Zone 8, about 2.54 miles (Figure 10). Finally, all of the shores of Assawoman Bay that lay within the study area, about 4.56 miles has been assigned Zone 9.

Figure 8. Aerial view of Turville Creek (diagonally) and downstream section of Herring Creek (left to right)

Figure 9. Aerial view of the left bank of St. Martin River

Figure 10. Aerial view of the eastern half of Isle of Wight (Zone 8)

III. HUMAN USE AND POPULATION

In the last three decades Worcester County has undergone significant change, especially in the northeastern sector where the study area is located. Easy access from two large metropolitan cities (Washington, DC and Baltimore) and beautiful coastal natural resources have resulted in the creation of a major recreation and tourism industry in this area. Today, recreation surpasses agriculture in terms of its overall contribution to the economy of the County. The shores of the study area are under development pressure because of their proximity to Ocean City. It is anticipated that as land in Ocean City becomes more expensive and scarce, the bay shorelines will receive spillover growth. It has been projected that this part of the County will witness a 25 percent increase in population by the year 2005 (CDP, 1989).

Today, about 7.5 miles or 17 percent of the 41 miles of the study area has been intensely developed (Figure 11). Canals have been created in some of the residential areas which allow residents water access to the bay. Most of these developed shorelines have been stabilized with bulkheads (Figure 12). The most developed shores of the study area are located along the shores of Isle of Wight Bay, the north bank of Turville Creek and Manklin Creek and the west bank of Herring Creek.

The Worcester County Comprehensive Development Plan (CDP, 1989) indicates that there are 6 land use types in the study area; Commercial Centers, Suburban, Agriculture, Suburban Residential, Rural Estate, and Conservation (Figure 13)). **Commercial Centers** are areas reserved for retail, service and office development. The only Commercial land use in the study area is located along Herring Creek, on both sides of Route 50, and accounts for 3.5 percent of the study area shoreline. **Suburban** land use accounts for only 1.5 percent of the study shoreline and is located on the east bank of Herring Creek. The suburban land use type was designed to anticipate the growth of Ocean City and permits the highest development densities. **Agriculture** land use is located along only 1 percent of the shoreline in the study area.

Most of the study shoreline (58 percent) falls under the **Suburban Residential** land use category. It accommodates a large portion of the county's population but development occurs at a lower density than the Suburban land use category (four units maximum per acre compared to six dwelling units per acre). **Rural Estate** land use also occurs along a large portion of the study area shoreline (30 percent). Residential development in this area is limited to lot sizes larger than one unit per two acres, which is larger than Suburban and Suburban Residential land use densities. Finally, the **Conservation** land use type comprises the Isle of Wight, about 6% of the total study shoreline. This land use category is reserved for areas which pose constraints to development and where development could have a significant adverse effect on the environment.

SUMMARY

- Rapid coastal changes are taking place today, and erosion and submergence at various rates are evident throughout the study area.

- Development pressures are increasing as Ocean City approaches saturation and new waterfront property becomes scarce.

- The steep slopes on some parts of the study area can be traced back to the Pleistocene shoreface (scarp) of ancient barrier islands.

- About 58 percent or 24 miles of the study area shoreline are wetlands based on the 1989 aerial photography.

- About 25 percent or 10 miles of the study area shoreline is sandy beaches or small bluffs, and non-marshy coasts.

- Today about 7.5 miles or 17 percent of the 41 miles of the study area is developed, most of it intense residential development.

- The most developed shores of the study area are the Isle of Wight Bay, the north bank of Turville Creek and Manklin Creek and the west bank of Herring Creek.

Figure 11. Aerial view of Ocean Pines, on the right bank of St. Martin River

Figure 12. Stabilization of shorelines with bulkhead

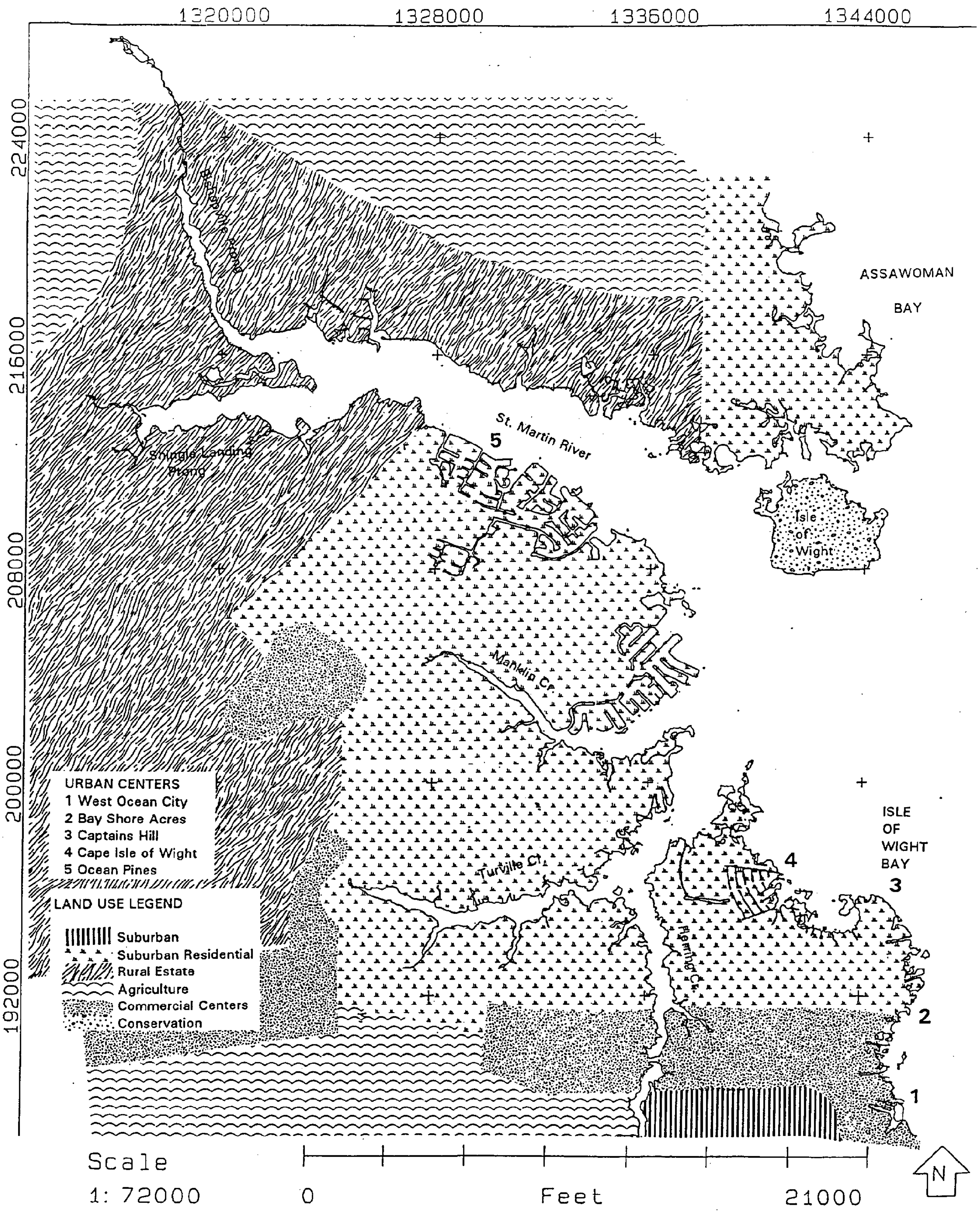


Figure 13. Land use categories in study area
(Source: CDP, 1989)

CHAPTER THREE
PRESENT RATES OF SHORELINE CHANGE

To determine rates of shoreline change, we employed our in-house Geographic Information System called Metric Mapping. Metric Mapping is capable of calculating shoreline change by comparing the spatial and temporal components of two or more shorelines. We began our analysis by digitizing shorelines off of NOAA-NOS T sheets (accurate historical maps), scale-corrected vertical aerial photographs, U.S.G.S. topographic sheets and other pertinent maps covering six historical dates: 1850, 1908, 1934, 1962, 1977 and 1989.

Metric Mapping requires that we digitize perpendicular lines to the shoreline, called transects. Metric Mapping intersects the transects with the different dated shorelines and estimates the horizontal distance between these shorelines. The distance is then divided by the time period between the two shorelines and a shoreline change rate is assigned to the particular transect. To cover the 41 miles of the study area shoreline, 215 transects were equally spaced approximately 1000 feet apart (Figure 14).

In same cases, the rate of shoreline change was estimated by considering the geomorphology, topography and human activities in each transect in addition to the shoreline change values generated by Metric Mapping. For example, if an area has been developed (i.e., construction of bulkheads or marinas), we considered the shoreline change rate to correspond to the human modification of the shore, which is stable. Also, on those shores that were occupied by marshes according to 1850 maps, but were later destroyed, shoreline change rates were estimated for the present shoreline type and not for the historic marsh. All negative shoreline change values correspond to movement of the shoreline towards the land and is called erosion. All positive shoreline change values correspond to movement of the shoreline away from the land is called accretion.

Zone 1: Isle of Wight Bay Shores

Metric Mapping data showed that the rates of shoreline change for Zone 1 range from -3 ft/yr[1] to stable (Table 2)[2]. The erosion rate is high in this zone because most of the transects (70 percent) were calculated along marshy shorelines which seem to erode quicker than other shorelines. Erosion rates at marshy shorelines average -1.3 ft/yr in this zone (note marsh average, Table 2). A maximum erosion trend of -3 ft/yr in the area of Horn Island (transect 4, Table 2). Two communities, Cape Isle of Wight and Captains Hill, have armored their shoreline and thus, no

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[1] Negative numbers indicate erosional trends, while positive numbers represent accretion

[2] Tables 2 through 15 are located at the end of this chapter.

significant shoreline change has been observed in this area since 1962 (transects 10-12 and 18, Table 2).

Zone 2: Turville Creek shores

In Zone 2, along the north and south banks of Turville Creek, shoreline change rates remained consistent between the two banks (Tables 3 and 4). Along the south bank, half of the transects were calculated along marshy areas. These transects exhibited erosion rates that average -0.6 ft/yr (transects 24-26 and 29, 55-58, Table 3). The trend diminishes upstream. Shoreline change continues even though the shoreline has been stabilized at a small area of development near the mouth of Herring Creek (transects 27, Table 3). Along the shoreline at the upper part of the Creek, where there exists three race tracks, erosion rates vary from -0.5 ft/yr to stability (transect 61-67, Table 3).

The shoreline on the upper part of the north bank of Turville Creek has been armored with bulkheads and small seawalls as indicated by maps from 1962. As a result no significant shoreline change has been observed since this time (transects 68-77, Table 4). Marshes dominate the shoreline along the mouth of the north bank of the Creek (transects 78 to 85, Table 4). Erosion rates increase downstream in this area and average -0.8 ft/yr, with a maximum of -1.8 ft/yr.

Zone 3: Herring Creek shores

Herring Creek, Zone 3, is a tributary of Turville Creek and is geomorphologically similar. The mouth of the Creek is fringed by marshes, while the middle section is occupied by development. Along the shores of the upper part of the Creek there exists agricultural fields and no marsh development.

The shoreline of the east bank of the Creek is eroding at rates from -2 ft/yr to -1.1 ft/yr and decreases upstream (transects 30 to 42, Table 5). The developed shoreline of the middle part of the Creek is eroding at rates ranging from -0.5 to -0.2 ft/yr (transects 38 and 39, Table 5).

The west bank of the Creek is eroding at an average rate of -0.3 ft/yr, less than the east bank of the Creek (Table 6). The middle part of this bank has been developed and has not changed significantly since 1934. The marshy shores (transects 49 to 54, Table 6) near the mouth of the Creek have eroded at a rate ranging from -0.9 to -0.2 in the last 139 years (1850-1989).

Zone 4: Manklin Creek shores

Zone 4, Manklin Creek, extends from transect 86 to 100 (Tables 7 and 8). The south bank is occupied by marshes and a few areas of development. The shoreline at the mouth of the Creek, near Isle of Wight Bay, is eroding at rates ranging from -1.5

ft/yr to -0.5 ft/yr (transects 86-93, Table 7). Erosion rates diminish upstream especially where marshes are small and narrow because of steeply sloped banks.

The mouth of the north bank of Manklin Creek (Table 8) has been armored because of extensive residential development including many access canals. The shoreline at the upper part of the Creek is steeply sloped with narrow coastal marshes and is eroding at rates of -1.5 ft/yr (transect 97, Table 8).

Zone 5: St. Martin River shores

The south shores of the Saint Martin River are relatively stable although some areas are accreting (transects 101-107, 125-126, 132-133, Table 9). Only a small portion of the south bank of the Saint Martin River contains marshy shores, the rest has been developed into residential marinas with hard shoreline stabilization structures (Ocean Pines, between transect 103 and 104, Table 9). The marshy shores at the source of the River have been accreting or are stable as is evident from historical maps (transects 106-107, 125-126, 132-133, Table 9).

On the other hand, the north bank of the Saint Martin River has less development and more marshy shorelines. All transects here (from 150 to 165, Table 10) indicate erosion at rates higher than -1 ft/yr, with the exception of three transects (150, 151 and 164, Table 10) which show erosion rates of -0.5 ft/yr.

Zone 6: Shingle Landing Prong shores

Shingle Landing Prong is located on the upper part of the Saint Martin River. The steep slopes of the shores of this prong reduce the possibility for wetland expansion to upland areas as sea level rises. Transects at the mouth of the south bank of the prong (transects 108-111, Table 11) indicate erosional trends of about -0.5 ft/yr. At the upper part of the prong, accretional trends vary between 1.4 and 0.4 ft/yr (transects 112, 116-118, Table 11). The north bank of the prong (transects 119-124, Table 12) has steep slopes and small areas of marshes that are presently eroding at an average rate of -0.5 ft/yr.

Zone 7: Bishopville Prong shores

Bishopville Prong, Zone 7 (Table 13), is also part of the Saint Martin River basin. Its banks consist of steep slopes and a small marshy shoreline at the mouth of the prong. Transects on the west bank indicate a stable shoreline since 1934 (transects 134-139, Table 13). The east bank of the prong has been slightly eroding north of Daye Road but in general this bank is stable (transects 140-147, Table 13).

Zone 8: Isle of Wight

The Isle of Wight shoreline, Zone 8, is predominantly occupied by marshes except for the southern shore of the island. Erosion rates range from -0.4 to -2.5 ft/yr around the island (Table 14). The more exposed southern part of the island is experiencing the greatest erosion rates (transects 175-179, Table 14).

Zone 9: Assawoman Bay shores

Zone 9 encompasses the south shores of Assawoman Bay (Table 15). The slope of the coastline is gentle, very indented and fringed with marshes. The 5-foot contour lies about 4000 feet from the shore. Marshes are being lost due to erosion and submergence. More than 50 percent of the transects indicate erosion rates between -0.5 and -1.5 ft/yr for records between 1850 to 1989 (transects 186-188, 193-196, 202-203, 208-209, 211-214, Table 15). The lack of historical shoreline data for the northern section of the shoreline did not allow for a reliable estimate of long term shoreline change in this area.

SUMMARY

The mouth of the north bank of Saint Martin River appears to be the area where marshes are eroding most rapidly. Marshes are also eroding at the south shores of the Isle of Wight Bay, the west bank of the middle part of Herring Creek, the north bank of Manklin Creek, and the Isle of Wight.

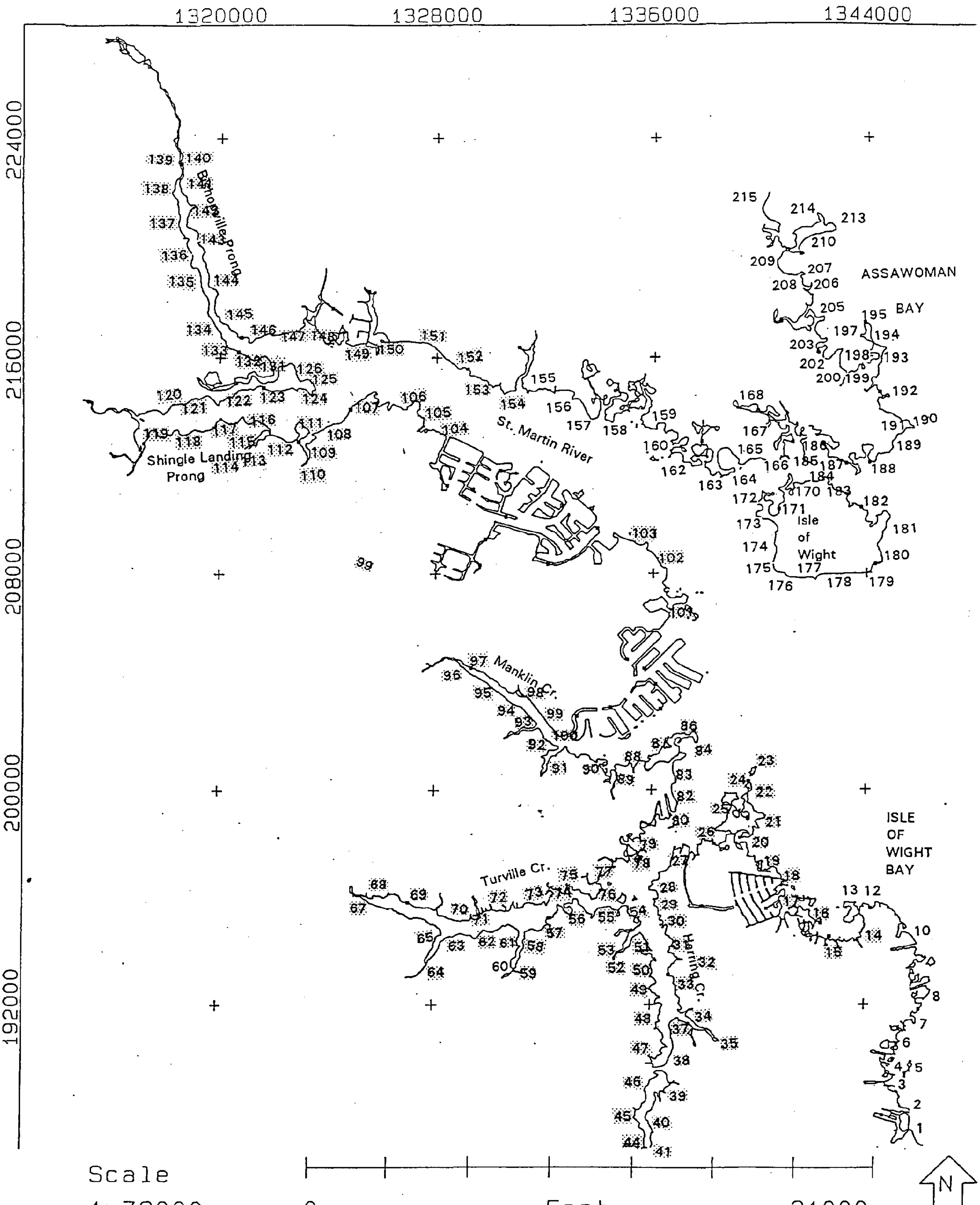

Figure 14. Location of transects

Table 2. Rates of Shoreline Change (feet/year)
Zone 1: Isle of Wight Bay Shores

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
1	Trees	-2	1908-1989	81
2	No Marsh	-1	1908-1989	81
3	Marsh	-1.0	1850-1989	139
4	Marsh	-3	1850-1989	139
6	Marsh	-3	1850-1989	139
7	Sandy beach	-0.6	1850-1989	139
8	Marsh	-0.8	1850-1989	139
9	Marsh	-1.2	1850-1989	139
10	Development	0	1962-1989	27
11	Development	0	1962-1989	27
12	Development	0	1962-1989	27
13	Marsh	-1.3	1850-1989	139
14	Marsh	0	1934-1989	55
15	Marsh	-1.6	1850-1989	139
16	Marsh	-0.9	1850-1989	139
17	Marsh	-0.6	1850-1989	139
18	Development	0	1962-1989	27
19	Marsh	-0.9	1850-1989	139
21	Marsh	-0.3	1850-1989	139
22	Marsh	-1.5	1850-1989	139
23	Marsh	-2.2	1850-1989	139

Overall Average -1.0
Marsh Average -1.3

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 3. Rates of Shoreline Change (feet/year)
Zone 2: Turville Creek (South Bank)

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
24	Marsh	-0.6	1850-1989	139
25	Marsh	-1.0	1850-1989	139
26	Marsh	-1.2	1850-1989	139
27	Development	-1.0	1934-1989	55
28	Development	0	1934-1989	55
29	Marsh	-0.8	1850-1989	139
55	Marsh	0	1850-1989	139
56	Marsh	0	1934-1989	55
57	Marsh	-0.8	1934-1989	55
58	Marsh	-0.7	1934-1989	55
61	Filling,NM	-0.3	1934-1989	55
62	Filling,NM	-0.5	1934-1989	55
63	Trees,NM	0	1934-1989	55
65	Filling	-0.3	1934-1989	55
66	Filling	0	1934-1989	55
67	Filling	0	1934-1989	55

Overall Average -0.5
Marsh Average -0.6

Note:
NM: No Marsh
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 4. Rates of Shoreline Change (feet/year)
Zone 2: Turville Creek (North Bank)

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
68	Development	0	1962-1989	27
69	Development	0	1962-1989	27
70	Development	0	1934-1989	55
71	Development	0	1962-1989	27
72	Development	0	1962-1989	27
73	Trees	-0.8	1934-1989	55
74	Development	0	1934-1989	55
75	Marsh	-0.6	1934-1989	55
76	Marsh	-0.5	1934-1989	55
77	Development	-0.7	1850-1989	139
78	Marsh	-1.5	1850-1989	139
79	Marsh	-1	1850-1989	139
80	Marsh	-1.8	1850-1989	139
81	Marsh	-0.3	1934-1989	55
82	Sandy	-0.2	1850-1989	139
83	Sandy	-0.9	1850-1989	139
84	Marsh	-0.9	1850-1989	139
85	Marsh	0	1850-1989	139

Overall Average -0.5
Marsh Average -0.8

OVERALL AVERAGE -0.5
MARSH AVERAGE -0.7

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 5. Rates of Shoreline Change (feet/year)
Zone 3: Herring Creek (East Bank)

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
30	Marsh	-1.6	1850-1989	139
31	Marsh	-2.0	1850-1989	139
32	Marsh	-1.4	1850-1989	139
33	Marsh	-1.1	1850-1989	139
37	Trees,NM	0.2	1850-1989	139
38	Field	-0.2	1850-1989	139
39	Field	-0.5	1850-1989	139
40	Field	-0.2	1934-1989	55
41	Trees	0.9	1934-1989	55
42	Marsh	-0.3	1934-1989	55

Overall Average -0.6
Marsh Average -1.3

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 6. Rates of Shoreline Change (feet/year)
Zone 3: Herring Creek (West Bank)

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
43	Fringe Marsh	1.0	1934-1989	55
44	Trees	-0.4	1934-1989	55
45	Development	0	1934-1989	55
46	Development	0	1934-1989	55
47	Development	0	1934-1989	55
48	Development	-0.5	1934-1989	55
49	Marsh	-0.7	1850-1989	139
50	Marsh	-0.9	1850-1989	139
51	Marsh	-0.2	1850-1989	139
52	Marsh	-0.4	1850-1989	139
53	Marsh	-0.5	1850-1989	139
54	Marsh	-0.4	1850-1989	139

Overall Average -0.3
Marsh Average -0.3

OVERALL AVERAGE -0.4
MARSH AVERAGE -0.7

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 7. Rates of Shoreline Change (feet/year)
Zone 4: Manklin Creek (South Bank)

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
86	Marsh	-1.5	1850-1989	139
87	Marsh	-1.5	1934-1989	55
88	Fringe Marsh	-0.5	1850-1989	139
89	Marsh	-0.5	1934-1989	55
90	Fringe Marsh	-0.6	1934-1989	55
92	Marsh	0.3	1934-1989	55
93	Fringe Marsh	-0.5	1934-1989	55
94	Fringe Marsh	0	1934-1989	55
95	Fringe Marsh	0	1934-1989	55
96	Fringe Marsh	0	1934-1989	55

Overall Average -0.5
Marsh Average -0.5

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 8. Rates of Shoreline Change (feet/year)
Zone 4: Manklin Creek (North Bank)

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
97	Marsh	-1.5	1934-1989	55
98	Marsh	-1.4	1934-1989	55
99	Development	-1.3	1934-1989	55
100	Development	0	1934-1989	55

Overall Average -1.1
Marsh Average -1.5

OVERALL AVERAGE -0.6
MARSH AVERAGE -0.6

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 9. Rates of Shoreline Change (feet/year)
Zone 5: St. Martin River (South Bank)

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
101	Marsh	-0.7	1934-1989	55
102	Sandy	0	1850-1962	112
103	Sandy	-1	1850-1962	112
104	Fringe Marsh	0	1934-1989	55
105	Marsh	-0.6	1850-1989	139
106	Marsh	0	1850-1989	139
107	Fringe Marsh	0.2	1850-1989	139
125	Fringe Marsh	0.8	1934-1989	55
126	Sandy	0.9	1934-1989	55
132	Trees	0	1934-1989	55
133	Trees	0.8	1934-1989	55

Overall Average 0.03
Marsh Average -0.06

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 10. Rates of Shoreline Change (feet/year)
Zone 5: St. Martin River (North Bank)

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
148	Development	-1.4	1934-1989	55
150	Fringe Marsh	-0.6	1934-1989	55
151	Fringe Marsh	-0.5	1934-1989	55
152	Fringe Marsh	-1.3	1934-1989	55
153	Marsh	-2.2	1850-1989	139
154	Marsh	-3.2	1850-1989	139
155	Marsh	-3.1	1850-1989	139
156	Marsh	-2.9	1850-1989	139
157	Marsh	-1.3	1850-1989	139
158	Marsh	-3.3	1850-1989	139
159	Marsh	-1.3	1850-1989	139
160	Marsh	-1.6	1850-1989	139
161	Marsh	-2.2	1850-1989	139
162	Marsh	-1.6	1850-1989	139
163	Marsh	-1.4	1850-1989	139
164	Marsh	-0.7	1850-1989	139
165	Marsh	-1.7	1850-1989	139

Overall Average -1.8
Marsh Average -1.8

OVERALL AVERAGE -1.1
MARSH AVERAGE -1.3

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 11. Rates of Shoreline Change (feet/year)
Zone 6: Shingle Landing Prong (South Bank)

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
108	Development	-0.5	1934-1989	55
109	Narrow Marsh	-0.7	1934-1989	55
110	Trees	-1	1934-1989	55
111	Trees	0	1934-1989	55
112	Sandy	0	1934-1989	55
116	Trees	1.4	1934-1989	55
117	Filling	0.4	1934-1989	55
118	Trees	0.6	1934-1989	55

Overall Average 0.02
Marsh Average -0.7

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 12. Rates of Shoreline Change (feet/year)
Zone 6: Shingle Landing Prong (North Bank)

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
119	Marsh	-0.6	1934-1989	55
120	Trees	0.3	1934-1989	55
121	Trees	-1.1	1934-1989	55
122	Marsh	-0.5	1934-1989	55
123	Trees	0	1934-1989	55
124	Fringe Marsh	-1.3	1934-1989	55

Overall Average -0.5
Marsh Average -0.8

OVERALL AVERAGE -0.2
MARSH AVERAGE -0.8

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 13. Rates of Shoreline Change (feet/year)
Zone 7: Bishopville Prong (West Bank)

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
134	Trees	0	1934-1962	28
135	Trees	0	1934-1962	28
136	Trees	0	1934-1962	28
137	Trees	0	1934-1962	28
139	Development	0	1934-1962	28

Overall Average 0
Marsh Average 0

Bishopville Prong (East Bank)

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
140	Trees	0	1934-1962	28
141	Trees	-1.3	1934-1962	28
142	Trees	-1.5	1934-1962	28
143	Trees	0	1934-1962	28
144	Trees	0	1934-1962	28
145	Trees	0	1934-1962	28
146	Marsh	-0.6	1934-1989	55
147	Narrow Marsh	0	1934-1962	28

Overall Average -0.4
Marsh Average -0.3

OVERALL AVERAGE -0.3
MARSH AVERAGE -0.3

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 14. Rates of Shoreline Change (feet/year)
Zone 8: Isle of Wight

TRANSECT	DESCRIPTION	RATE	DATES	YEARS
170	Marsh	-1.4	1850-1989	139
171	Marsh	-1.2	1850-1989	139
172	Fringe Marsh	0	1850-1989	139
173	Fringe Marsh	-0.7	1850-1989	139
174	Sandy beach	-1.7	1850-1989	139
175	Marsh	-1.7	1850-1989	139
176	Fringe Marsh	-2.5	1850-1989	139
177	Sandy beach	-1.8	1850-1989	139
178	Sandy beach	-1.9	1850-1989	139
179	Sandy beach	-1.4	1850-1989	139
180	Sandy beach	0.3	1850-1989	139
181	Sandy beach	-1.1	1850-1989	139
182	Marsh	-1.0	1850-1989	139
183	Marsh	-0.4	1850-1989	139
184	Marsh	-0.5	1850-1989	139

OVERALL AVERAGE -1.1
MARSH AVERAGE -1.0

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

Table 15. Rates of Shoreline Change (feet/year): Zone 9

TRANSECT	LOCATION	DESCRIPTION	RATE	DATES	YEARS
185	Isle of Wight (NE)	Road	-0.4	1850-1989	139
186	St. Martin Neck	Marsh	-1.1	1850-1989	139
187	St. Martin Neck	Marsh	-0.8	1850-1989	139
188	St. Martin Neck	Marsh	-0.9	1850-1989	139
189	St. Martin Neck/Drum Pt.	Marsh	0	1850-1989	139
190	St. Martin Neck/Drum Pt.	Fringe Marsh	0	1934-1989	55
191	St. Martin Neck	Fringe Marsh	0.5	1934-1989	55
192	St. Martin Neck	Marsh	0	1934-1989	55
193	Assawoman Bay	Marsh	-1.7	1850-1989	139
194	Assawoman Bay	Marsh	-0.7	1850-1989	139
195	Assawoman Bay	Marsh	-0.5	1850-1989	139
196	Assawoman Bay	Marsh	-1.5	1850-1989	139
197	Goose Pond	Marsh	-0.4	1850-1989	139
198	Goose Pond	Marsh	0	1850-1989	139
199	Goose Pond	Marsh	-0.2	1934-1989	55
200	Goose Pond	Marsh	-0.2	1850-1989	139
201	Goose Pond	Marsh	0	1850-1989	139
202	Goose Pond	Marsh	-0.5	1934-1989	55
203	Goose Pond	Marsh	-0.6	1850-1989	139
205	Goose Pond	Marsh	-0.4	1850-1989	139
206	Goose Pond	Marsh	-0.3	1850-1989	139
207	Goose Pond	Marsh	-0.4	1850-1989	139
208	Goose Pond	Marsh	-0.7	1850-1989	139
209	Goose Pond	Road	-0.6	1850-1989	139
210	Assawoman Bay	Sandy	4.4	1962-1989	27
211	Hills Island	Marsh	-0.5	1850-1989	139
212	Brady Island	Marsh	-1.7	1850-1989	139
213	Assawoman Bay	Marsh	-1.4	1962-1989	27
214	Peeks Creek	Marsh	-0.7	1962-1989	27
215	Peeks Creek	Marsh	-3.5	1962-1989	27

OVERALL AVERAGE -0.5
MARSH AVERAGE -0.7

Notes:
DATES refers to the dates of the information sources
YEARS refers to the time period between two sources

CHAPTER FOUR
PROJECTION OF FUTURE SHORELINE POSITION

In the previous section we described the rate of shoreline change in the study area. In this section we will estimate the future position of the shorelines based upon the past rate of change, topography, landform type, and projected sea level rise scenarios. Even though Maryland's Atlantic coastal bay region would be subject to all of the impacts associated with accelerated sea level rise (erosion, inundation, salt water intrusion, higher water tables, and increasing flooding and storm damage), this section considers potential increases in erosional trends and inundation impacts only.

I. EROSION/INUNDATION MODEL

Because erosion and inundation are complex processes, their contribution to coastal retreat as sea level rises is not entirely understood. To simplify these complex processes we assumed a simultaneous occurrence of both processes due to sea level rise for each scenario.

As we discussed in the last chapter, shoreline change rates for the study area were obtained through a comparison of historical maps and past sea level rise (please see tables 2-15). We assumed that one of the major factors causing erosion was sea level rise occurring during the historical period studied. Shoreline change rates can be projected into the future by first establishing a rule of thumb between shoreline change and sea level rise. For example, if a shoreline has eroded -200 feet in 100 years, as indicated by a historical maps, then the erosion rate for this shoreline is -2 ft/yr. At the same time, if during this same time period relative sea level rose by 1.3 ft, then for every 0.013 ft of sea level rise, the shore eroded by -2 feet. These values (0.013 ft/yr of sea level rise = -2 ft/yr of shoreline retreat) were then used as a rule of thumb to determine the future shoreline position in our study area. Relative sea level rise was obtained by adding eustatic or global sea level rise (0.6 ft) with the local rate of subsidence (0.7 ft). Erosion rates for the various sea level rise scenarios were calculated and are shown in Table 16 (the base year was 1989).

Table 16. Erosion Rate Estimates

Year	Relative Sea Level Rise (ft)	Erosion Rate (ft/yr)
Last 100 years	1.3	-2.0
2020	0.4	-2.0
	0.5	-2.5
2050	0.8	-2.0
	1.5	-3.8
2100	1.4	-1.9*
	1.7	-2.4
	3.0	-4.2
	4.4	-6.1

* Erosion rates for 2100 are based on 111 years. The baseline is 1989.

We drew shoreline profiles at several locations (Figure 15). Appendix A contains all of the profiles. These profiles were used to estimate inundation potential. The sea level rise scenario (y axis) was drawn on the profile and the inundated area was estimated (x axis). The study area shoreline is predominantly occupied by wetlands, but sandy shores are also present. Thus, it was necessary to establish two types of erosion rates: (1) for wetlands and (2) for sandy shores. Shorelines stabilized with engineering structures were assumed to remain stable as sea level rises. When projecting the position of a marshy shoreline, we discovered that erosion and inundation would destroy the marsh for sea level rise scenarios greater than 1.4 feet. Therefore, it was necessary to apply erosion rates for sandy shores obtained from nearby representative areas. A sea level rise of 1.4 feet is higher than the high mid-tidal range (1.1 feet) that determines the upland limit of today's marshes. This is discussed below.

A sample shoreline profile is provided as an example of how the erosion and inundation potential at wetland shorelines was determined (Figure 16). The profile was divided into three sections based on its elevation. A combination of erosion rates and inundation were used in each section to determine the future position of the shorelines. Sector A represents the lower part of the shoreline profile where wetlands are generally located. In this sector, the hypothetical shoreline position was estimated by adding inundation and shoreline regression due to erosion as determined by historical erosional trends. Sector B represents a steeper slope where wetlands will not be able to form, except as a narrow fringe marsh, as sea level rises. In this sector, the new shoreline position was estimated by adding inundation plus erosion rates calculated for sandy shores in nearby areas. We used erosion rates for sandy shores because we assumed that all marshes will be lost at this elevation and as a result, the shoreline will be sandy. Sector C represents the upland areas of the profile. If the slope was found to be gentle enough for new wetlands to form, erosion rates for the original marshy shore were used to determine the hypothetical shoreline position. If the slope was not gentle enough for wetland formation, no wetlands were allowed to form and erosion rates were applied from sandy shores of other nearby areas.

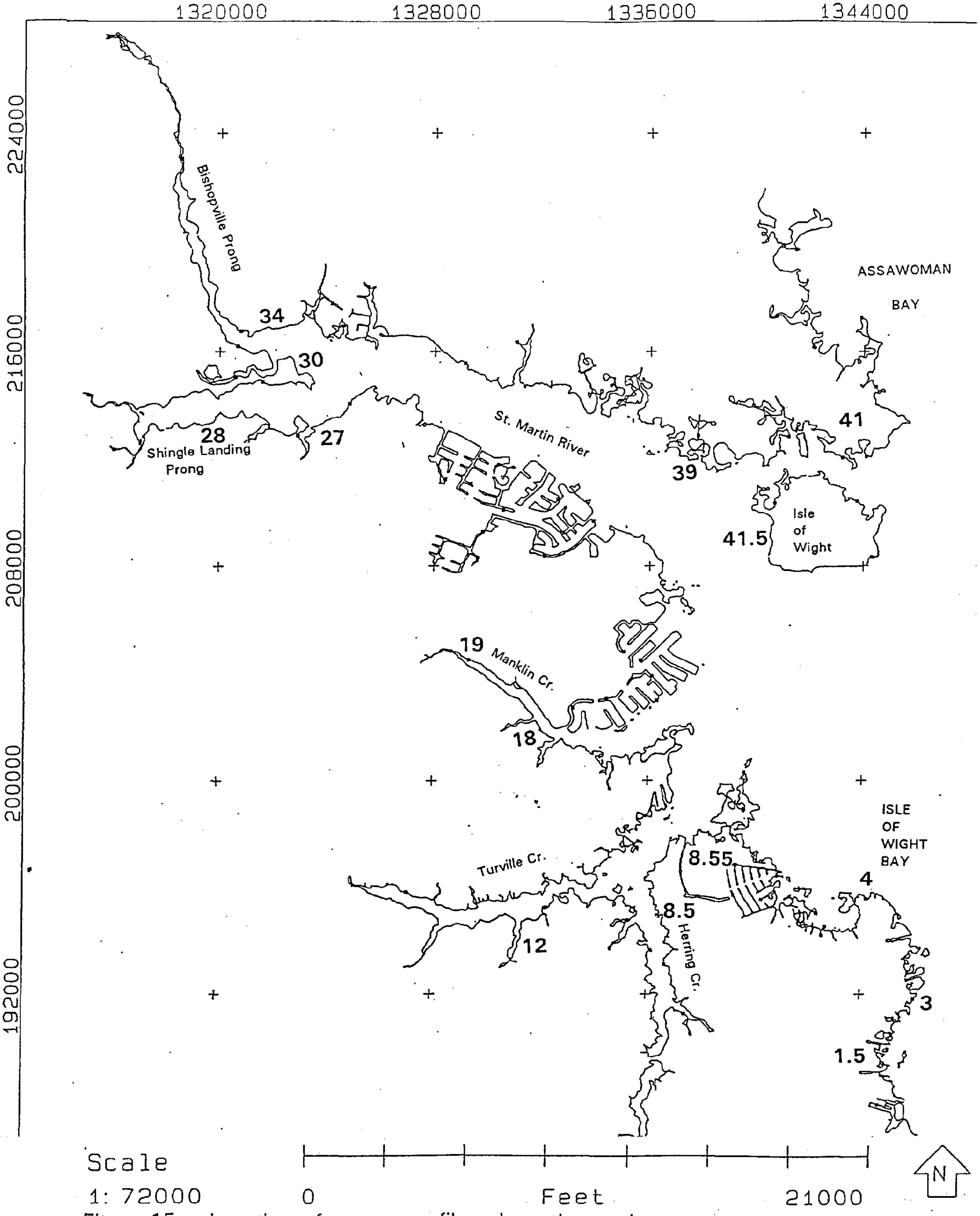

Figure 15. Location of survey profiles along the study shoreline

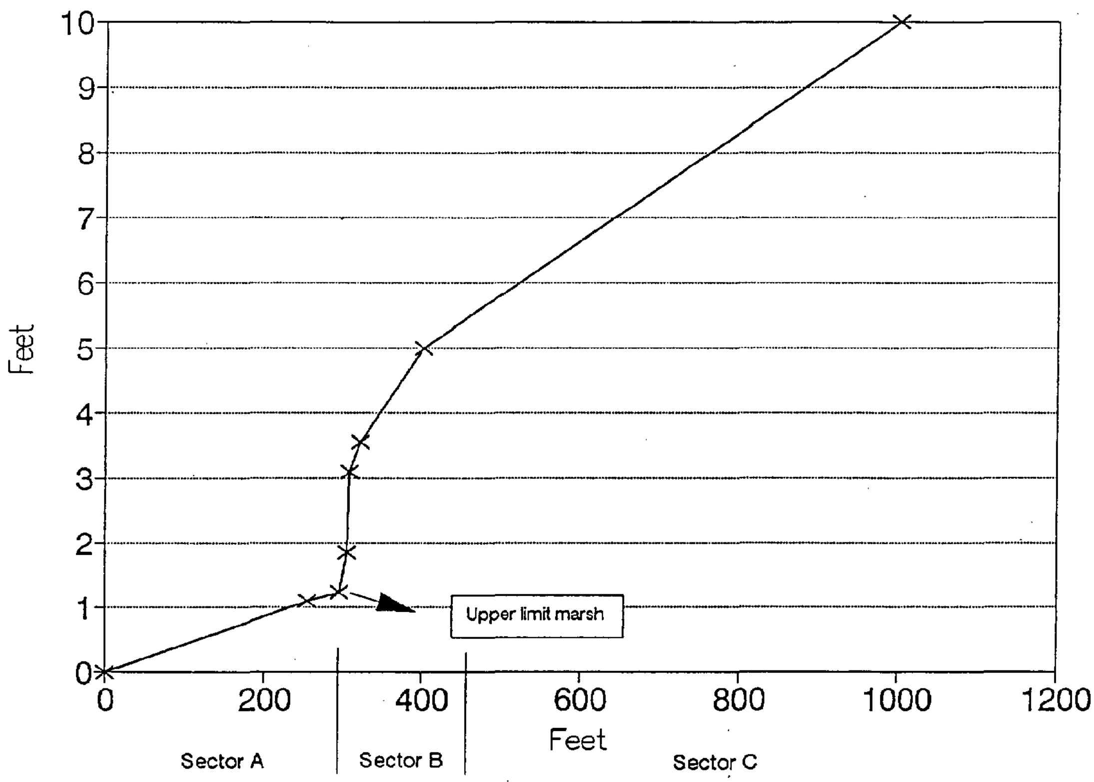

Figure 16. Representative profile and erosion/inundation model

II. FUTURE SHORELINE POSITIONS

We derived the hypothetical shoreline position for the various sea level rise scenarios by incorporating the historical shoreline change (erosion x the # of years from 1989) and the inundation potential derived from the topography of the shoreline for each transect. The shoreline position between the transects was interpolated. It was assumed that areas where development is presently located will maintain and upgrade their protection as sea level rises and therefore, no estimates for shoreline change were measured in these areas. Because interpolation and representative profiles were used, the position of hypothetical shorelines are not to be considered final but an estimation of the extent of shoreline retreat. A series of maps (Figures 17 through 44)[3] depicting the possible position of the shoreline, by zone, under different scenarios of sea level rise are included in this analysis.

Zone 1: Isle of Wight Bay shores (Figures 17, 18 and 19). Shoreline retreat in this zone averages between 100 and 150 feet, depending on the transect, for the year 2020; 250 to 400 feet for year 2050; and 400 to 780 feet for the year 2100. Shorelines adjacent to transect 4 and 19 (Figure 14) had the highest coastal retreat. The area of Bay Shore Acres (transect 7, Figure 14) showed the lowest retreat rate because of its steep shoreline profile.

Zone 2: Turville Creek shores (Figures 20, 21 and 22). Shoreline retreat on this Creek diminishes in a upstream direction because of steep slopes and a decrease in wetlands. Shoreline retreat rates are lower on the south bank of the Creek. On average, shoreline retreat varies from 35 to 200 feet for the year 2020, 60 to 500 feet for the year 2050 and 100 to 700 feet for the year 2100. Shoreline retreat was least along Gum Point Road and at the Ocean Downs Raceway. Wetland areas near the mouth of Herring Creek and the western end of Turville Creek had the highest shoreline retreat.

Zone 3: Herring Creek shores (Figures 23, 24 and 25). The most severe shoreline regression is possible near the mouth adjacent to Turville Creek. Shoreline regression in this region averages 150 to 200 feet for the year 2020, 350 to 500 feet for the year 2050, and 480 to 600 feet for the year 2100. The shores along the source of the Creek are protected, mainly around Route 50 and, therefore, the banks were assumed stable and no projections were made.

Zone 4: Manklin Creek shores (Figures 26, 27 and 28). More than 75 percent of the north bank of this Creek is developed and protected by engineering structures and therefore, no projections were made along this section. The south bank may retreat between 70 and 85 feet for the year 2020, 120 and 200 feet for the year 2050, and 180 to 660 feet for the year 2100.

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[3] These figures are located at the end of this section

Zone 5: St. Martin River shores (Figures 29, 30 and 31). The urban development of Ocean Pines, on the south bank of this river, accounts for more than 50 percent of this shoreline. No shoreline projections were estimated here because of the existence of hard structures. Wetlands on this bank exist only from transect 104 to 107 (Figure 14). Historical shoreline analysis indicates very low rates of coastal erosion. The north bank of the river starting on transect 150 (Figure 14) and continuing downstream is occupied by one of the most extensive wetlands in the study area. Aerial photography and field surveys indicate the presence of inland ponding. This area, together with zone 9, can expect a significant amount of shoreline retreat as sea level rises. Average shoreline retreat may run between 350 and 450 feet for the year 2020, 560 to 850 feet for the year 2050 and 840 to 1600 feet for the year 2100. According to the analysis, the western end of St. Martin Neck, where Isle of Wight Road (golf course) is located, could be breached and as a result the area could be converted into an island. The highest point is about 5 feet above present sea level along the road. Figure 32 shows an aerial photograph of St. Martin Neck.

Zone 6: Shingle Landing Prong shores (Figures 33, 34 and 35). The shores of Shingle Landing Prong have steep slopes and small areas of fringe marsh. The model projected small changes in the position of its present shoreline. On average the shoreline could retreat between 20 to 50 feet for the year 2020, 40 to 80 feet for the year 2050 and 50 to 150 feet for the year 2100.

Zone 7: Bishopville Prong shores (Figures 36, 37 and 38). Bishopville Prong has banks with steep slopes and some low-lying areas. Shoreline retreat projections were made only for the lower part of the east bank of the prong (transects 146 and 147, Figure 14). Here, the shoreline may retreat between 30 to 50 feet for the year 2020, 70 to 130 feet for the year 2050 and 130 to 200 feet for the year 2100.

Zone 8: Isle of Wight Island (Figures 39, 40 and 41). Shoreline retreat on this island will be greatest on the western shore, but shoreline retreat will also occur on the east and northwest shores. The southern shores of the island are expected to retreat the least because they consist of steep slopes. The highest point of the island barely exceeds 10 feet above present sea level and because most of the shores have very gentle slopes the island is vulnerable to even low levels of inundation. On average, the projected shoreline retreat for the island varies between 130 and 160 feet for the year 2020, 250 and 420 feet for the year 2050 and 380 and 840 feet for the year 2100.

Zone 9: Assawoman Bay shores (Figures 42, 43 and 44). The shores of this bay contain extensive wetlands with very gentle slopes that decrease northward along the shore. Wetland ponding is already occurring as shown by aerial photography (Figure 45). Sea level rise could have catastrophic consequences in this area because of the shore's low elevation and high rates of erosion. Average shoreline retreat projections vary from 300 to 400 feet for the year 2020, 600 to 1000 feet for the year 2050 and 900 to 1400 feet for the year 2100.

Legend clarification for the following maps (fig 17-31, 33-44).

The shoreline position for each map is based on the hypothetical sea level rise value, *historical shore erosion and inundation.*

For the year 2020

Present Trend	= 0.4 ft. of sea level rise (SLR)
Most Likely	= 0.5 ft SLR

For the year 2050

Present Trend	= 0.8 ft SLR
Most Likely	= 1.5 ft SLR

For the year 2100

Present Trend	= 1.4 ft SLR
Low Scenario	= 1.7 ft SLR
Most Likely	= 3 ft SLR
High Scenario	= 3.7 ft SLR

Present Protection/Future Protection = for all maps the hypothetical shoreline position was not calculated in these areas because these areas are protected by structural shoreline protection. The authors assumed that these structures will be upgraded to accommodate higher water levels.

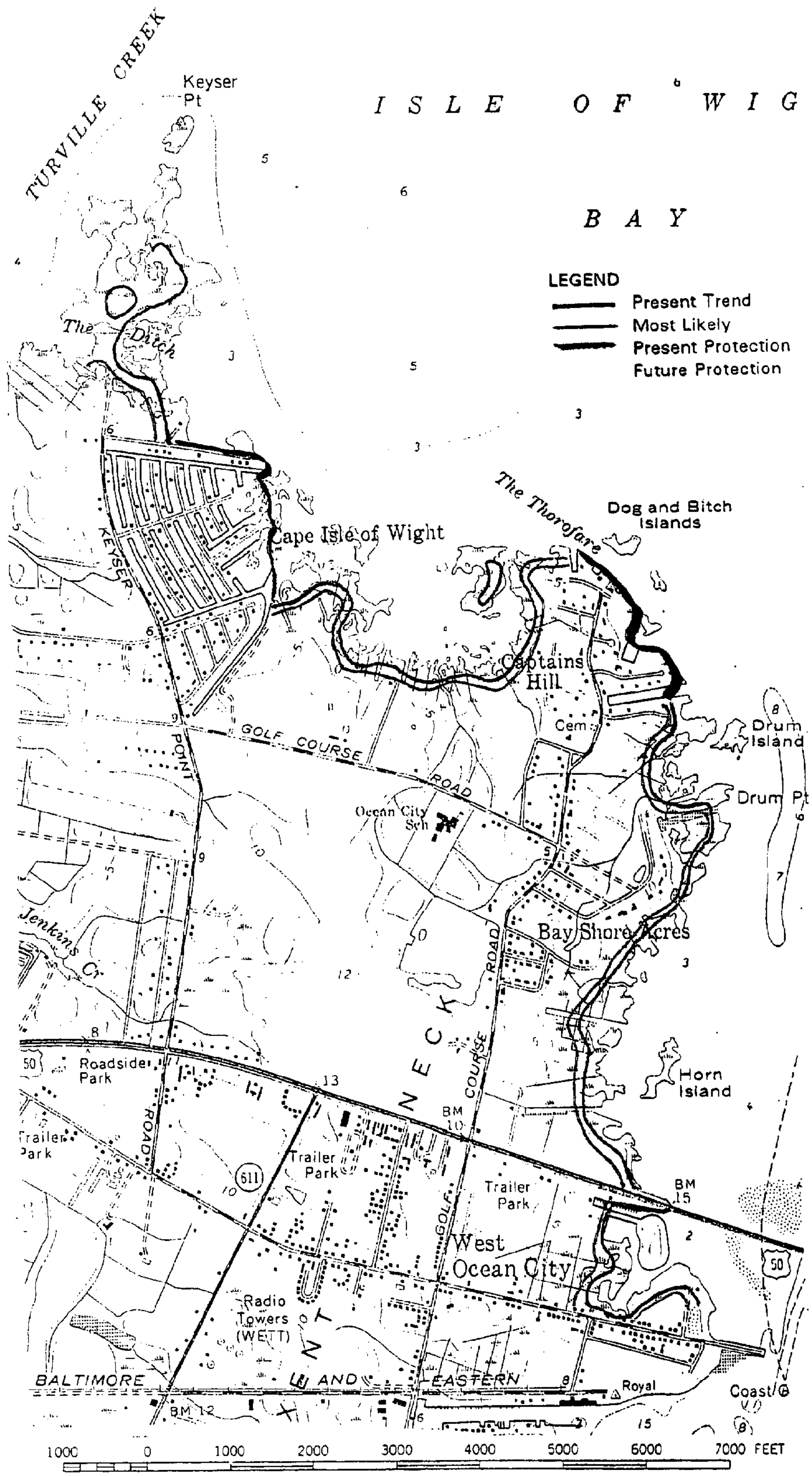

Figure 17. Zone 1: Estimated shoreline positions for the year 2020

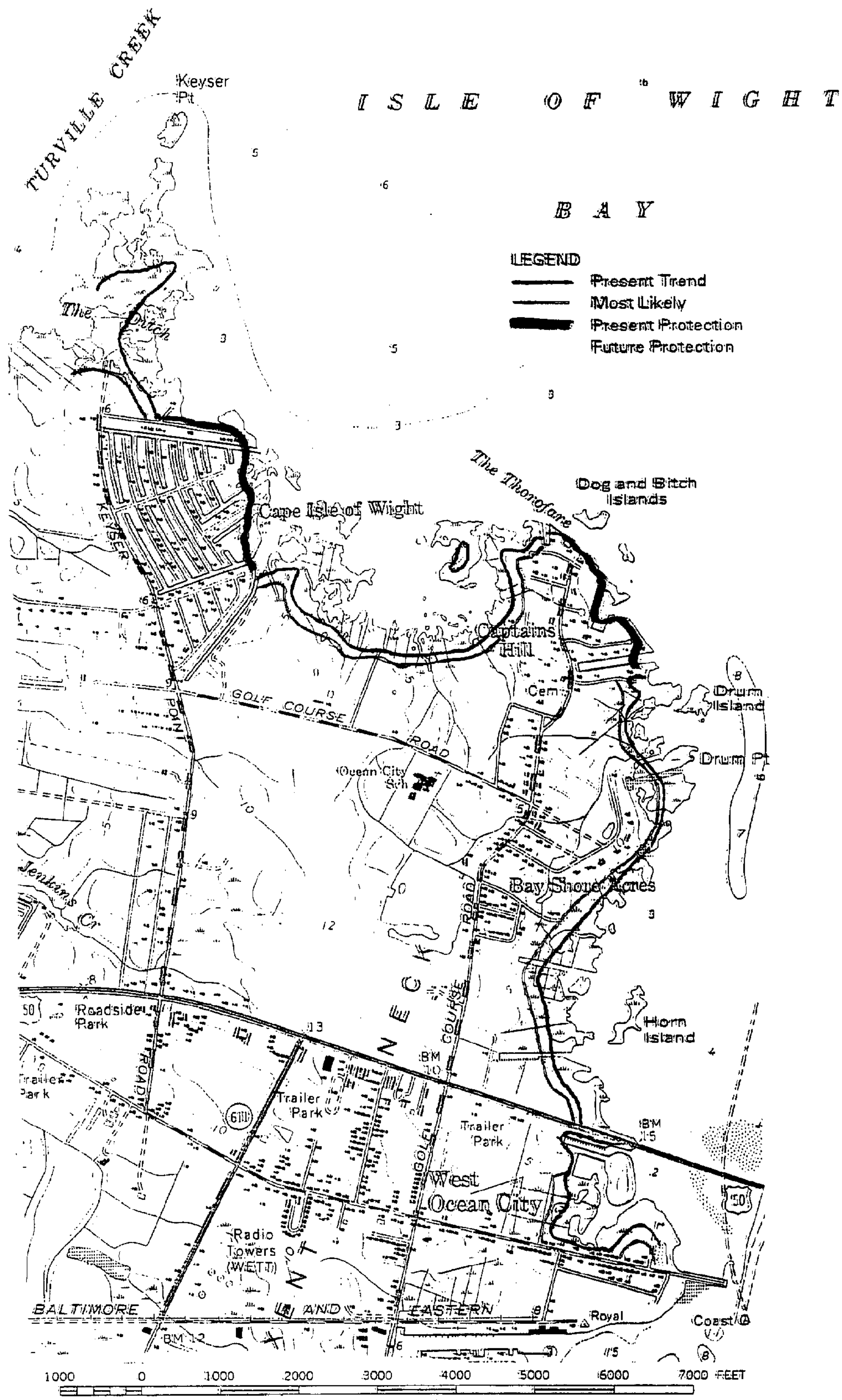

Figure 18. Zone 1: Estimated shoreline positions for the year 2050

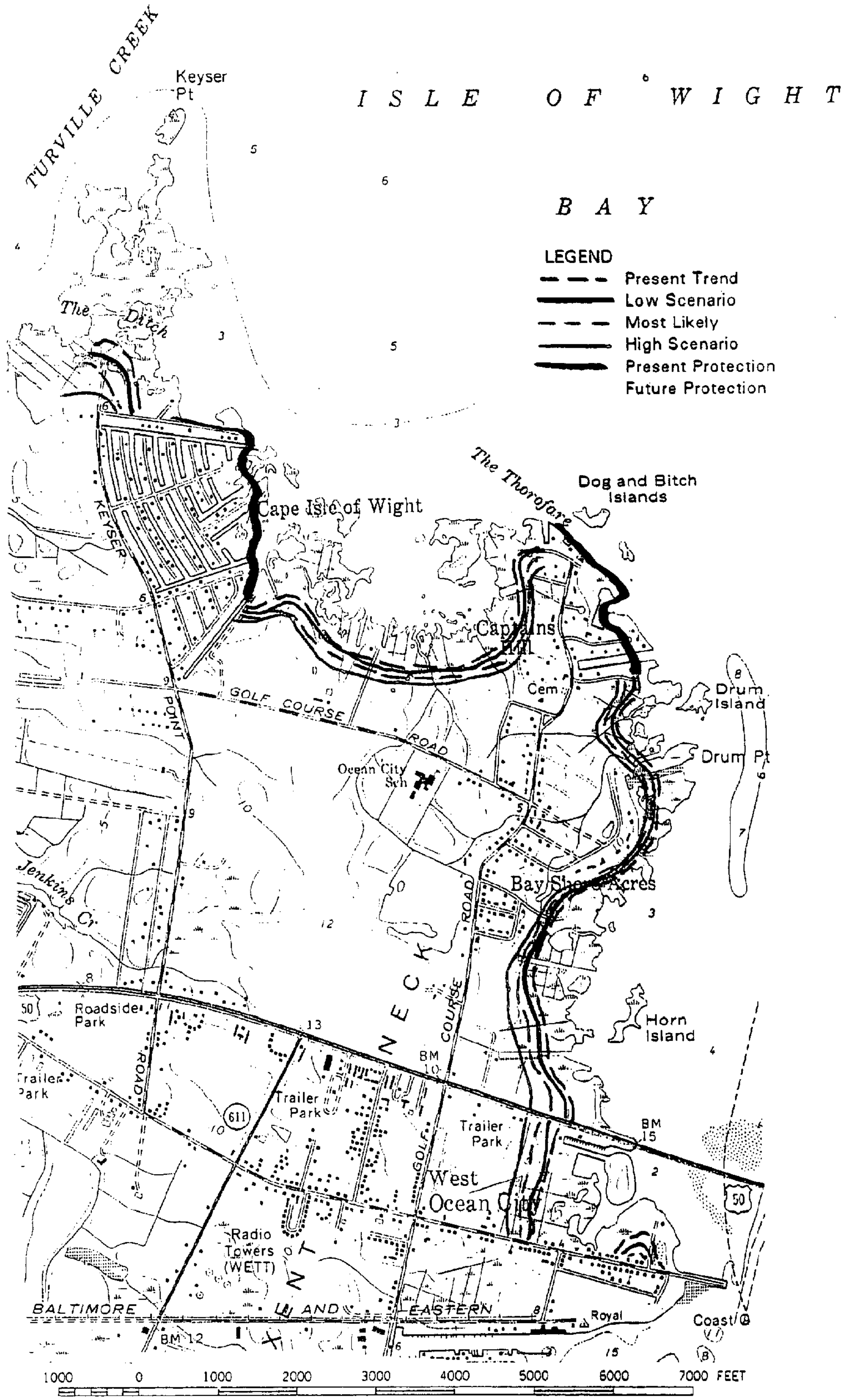

Figure 19. Zone 1: Estimated shoreline positions for the year 2100

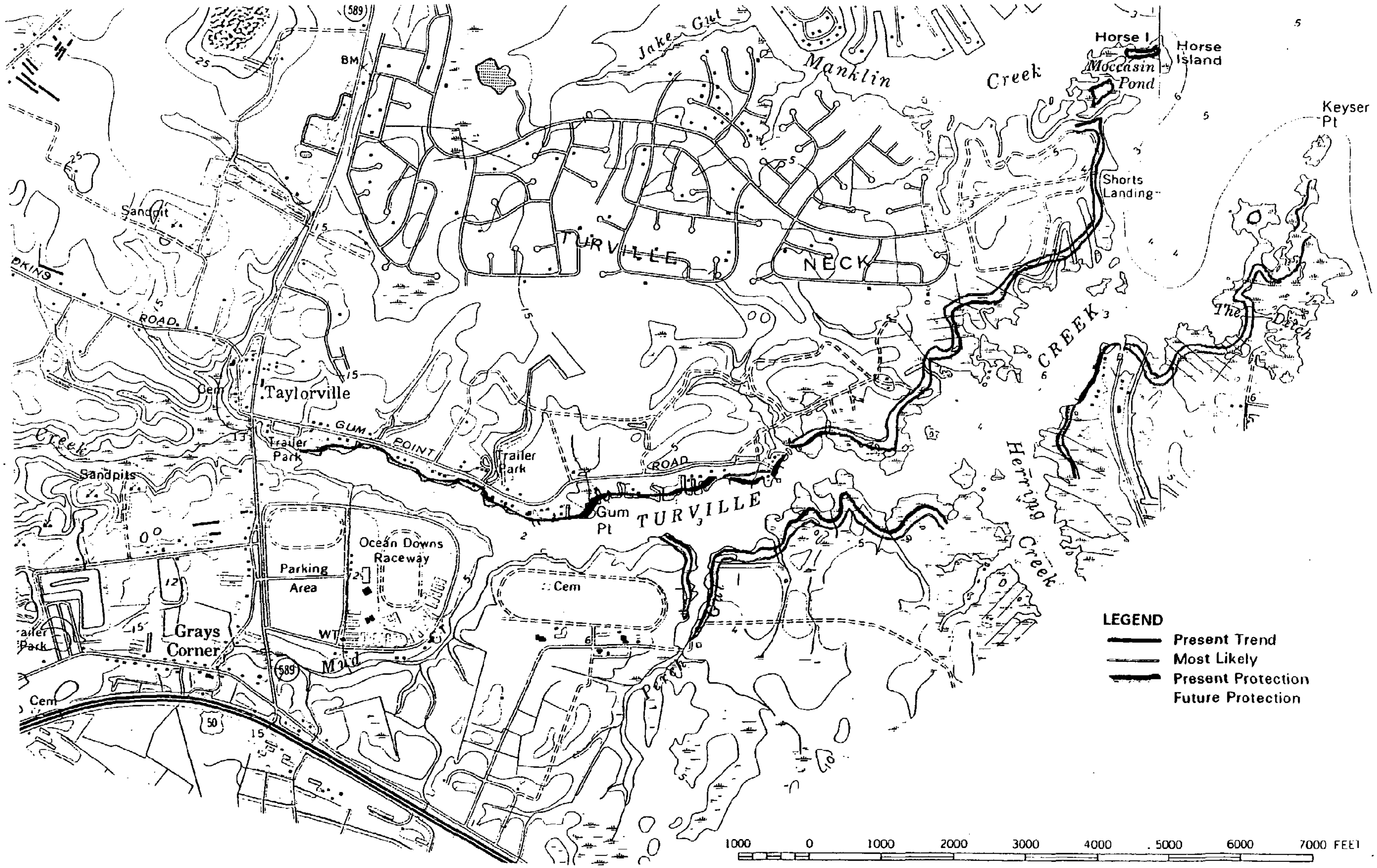

Figure 20. Zone 2: Estimated shoreline positions for the year 2020

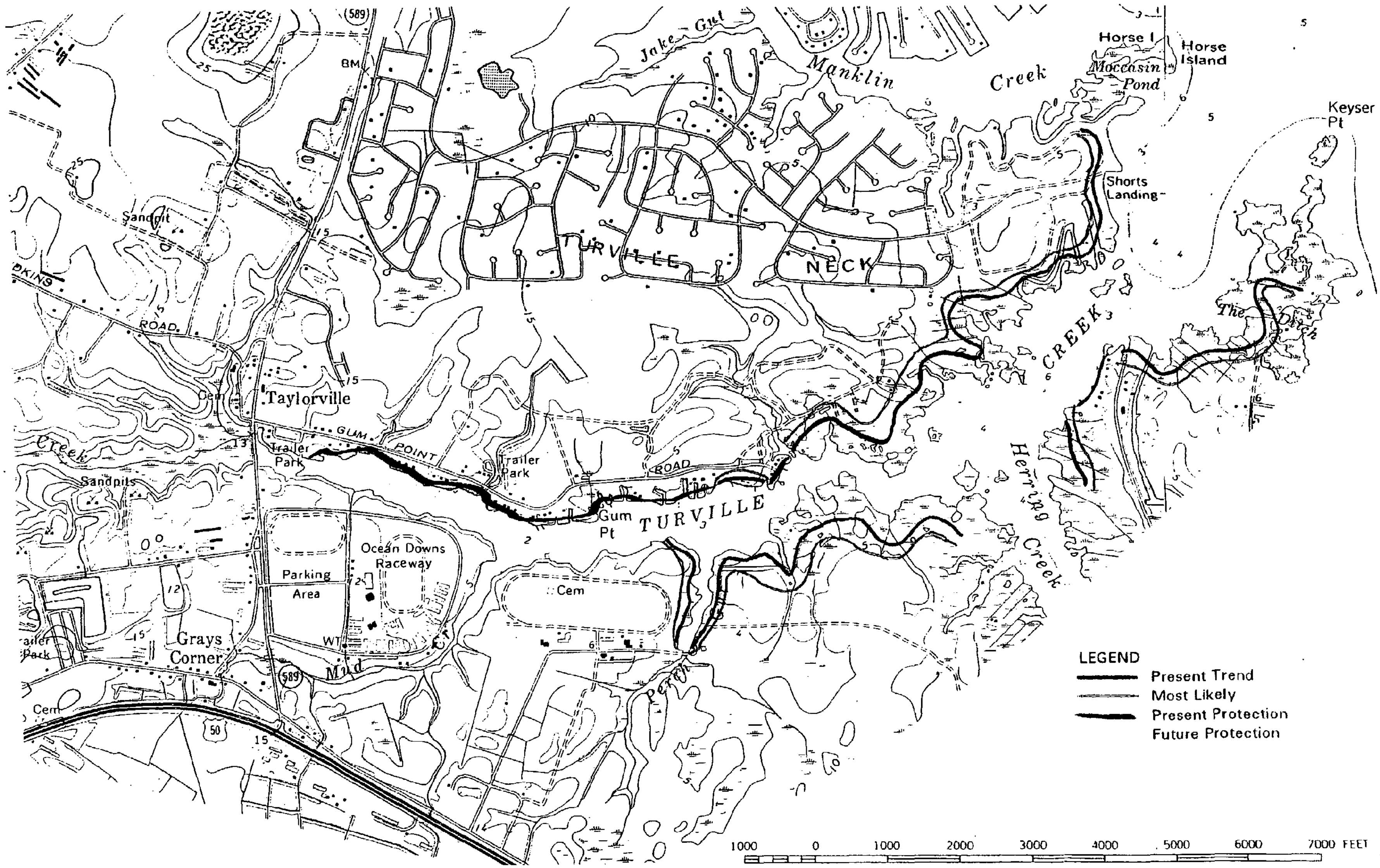

Figure 21. Zone 2: Estimated shoreline positions for the year 2050

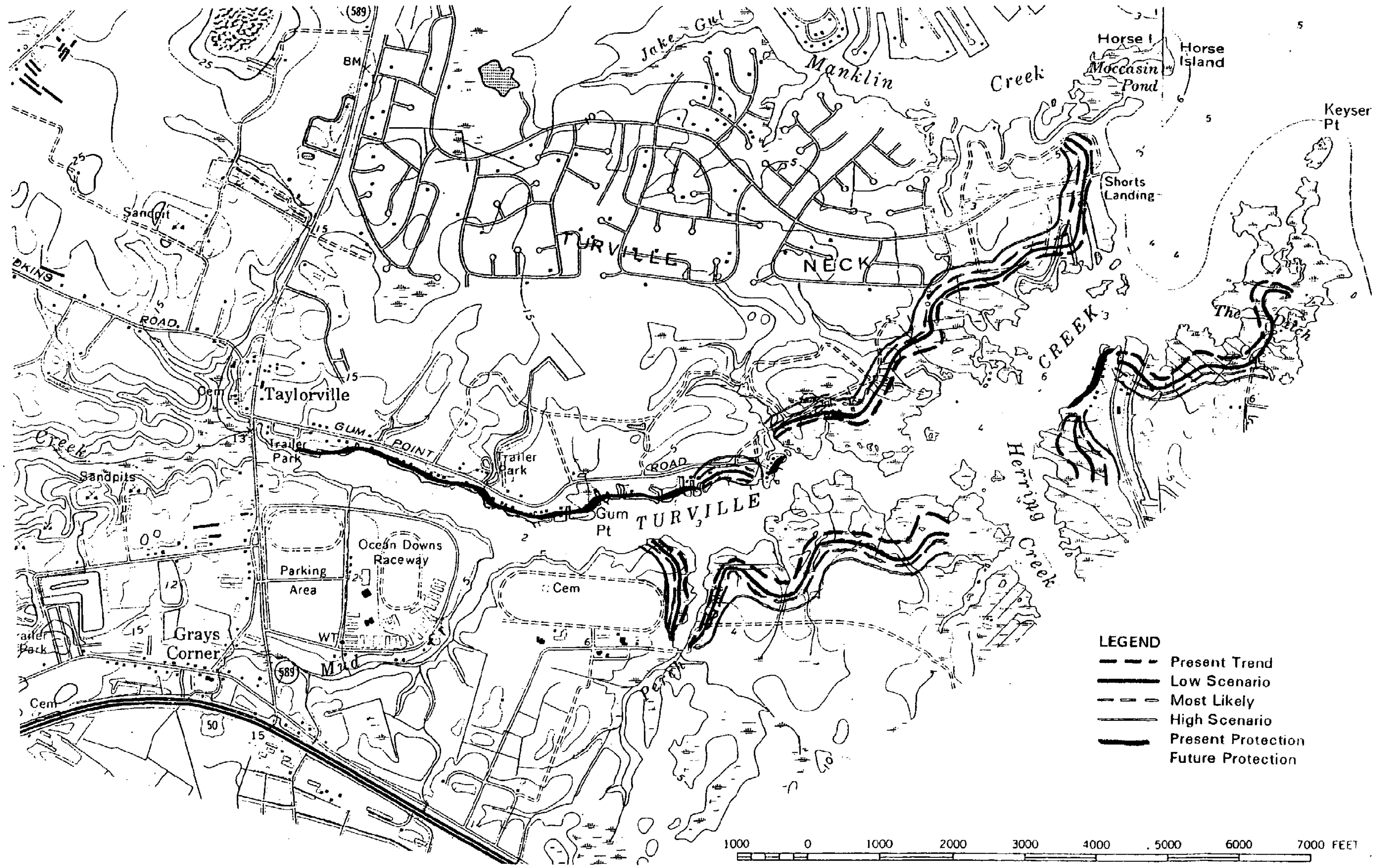

Figure 22. Zone 2: Estimated shoreline positions for the year 2100

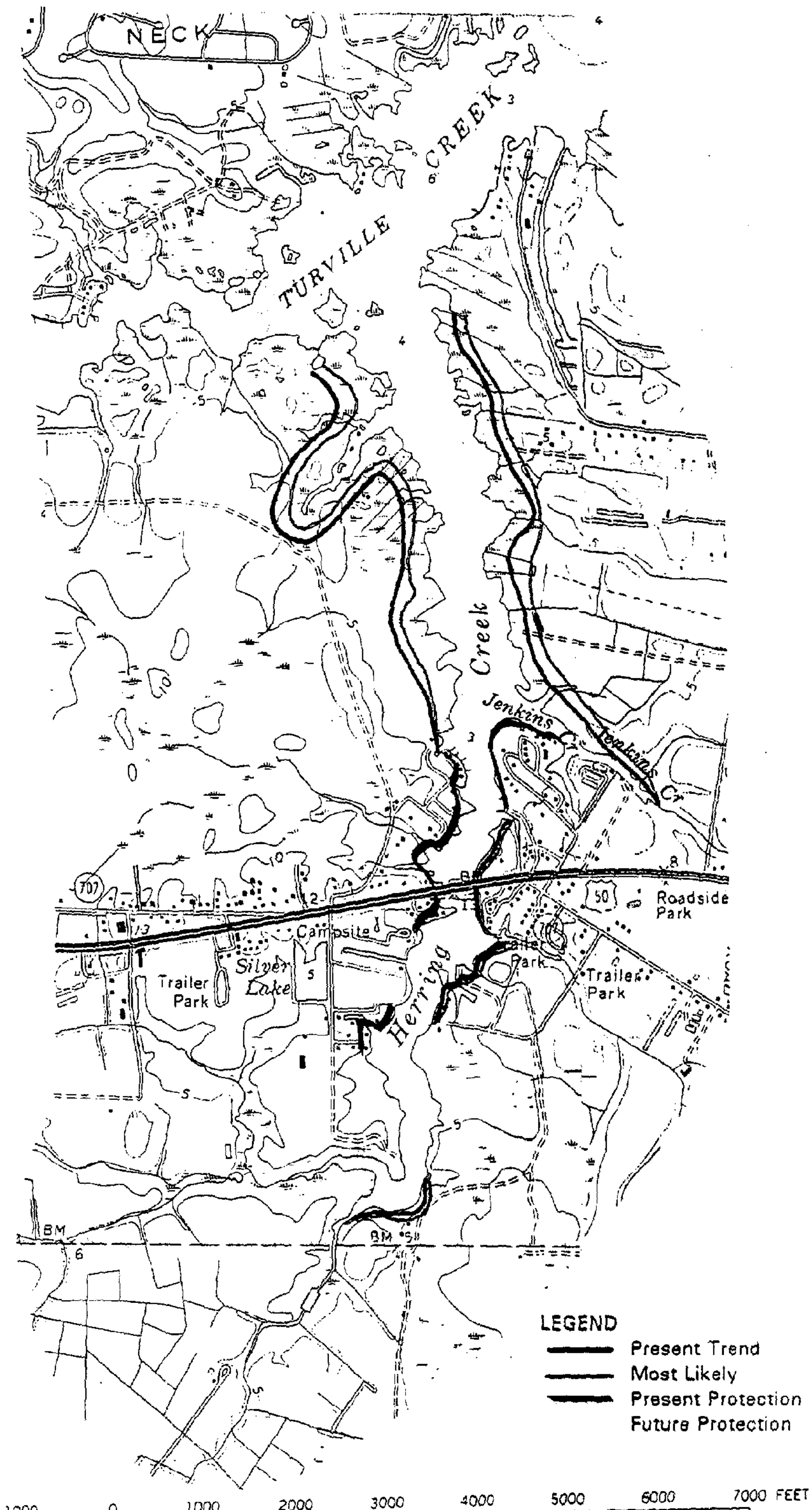

Figure 23. Zone 3: Estimated shoreline positions for the year 2020

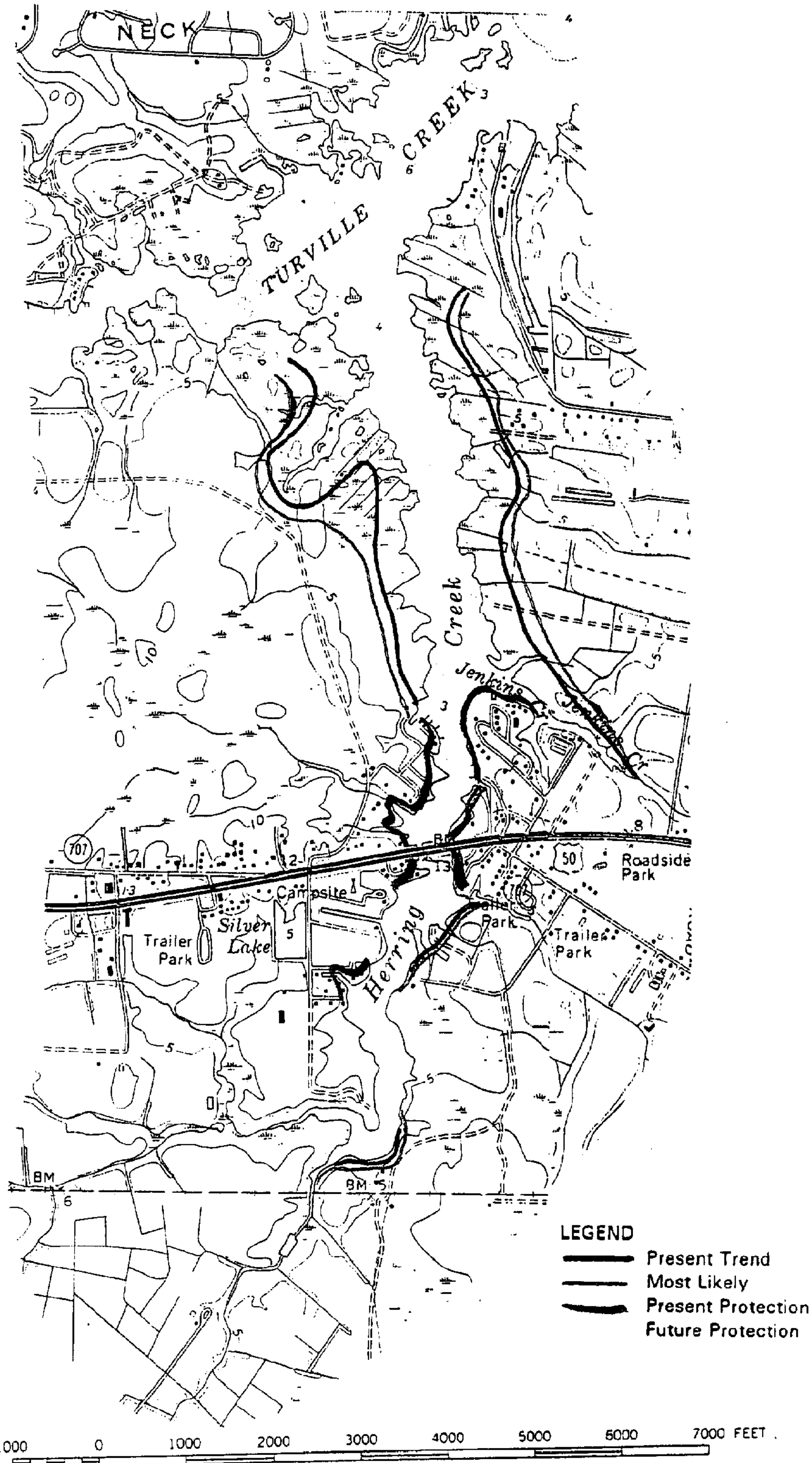

Figure 24. Zone 3: Estimated shoreline positions for the year 2050

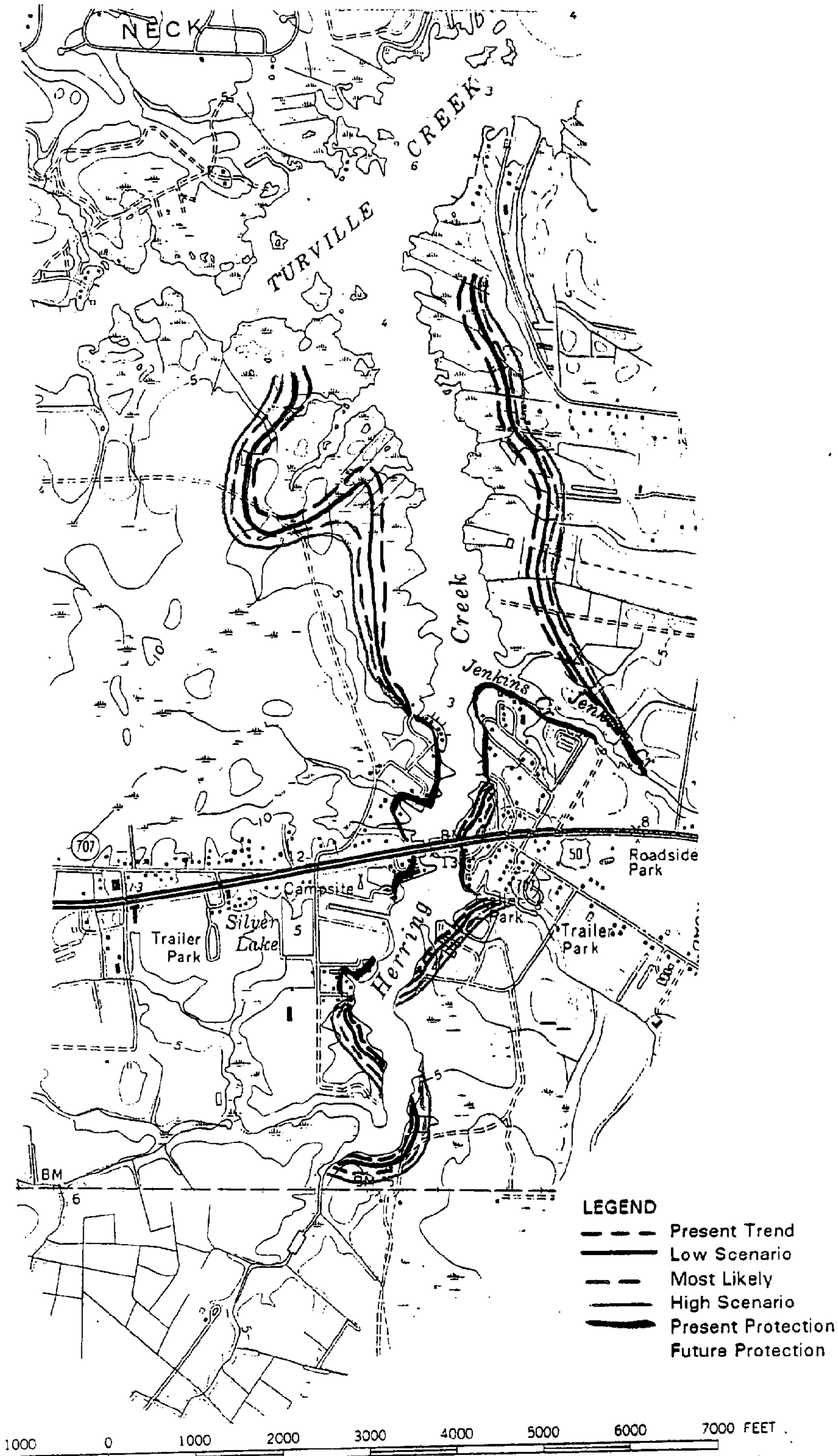

Figure 25. Zone 3: Estimated shoreline positions for the year 2100

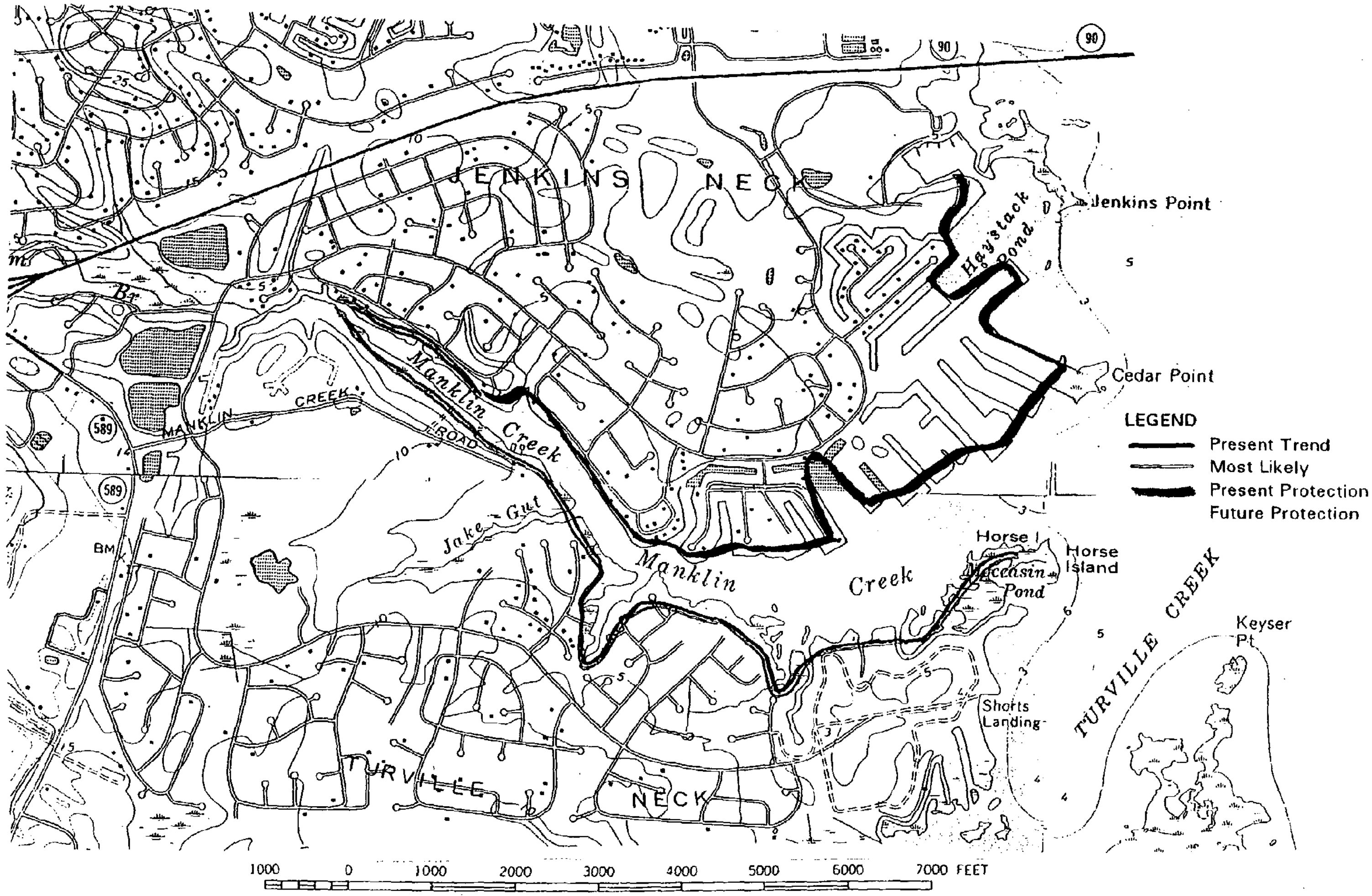

Figure 26. Zone 4: Estimated shoreline positions for the year 2020

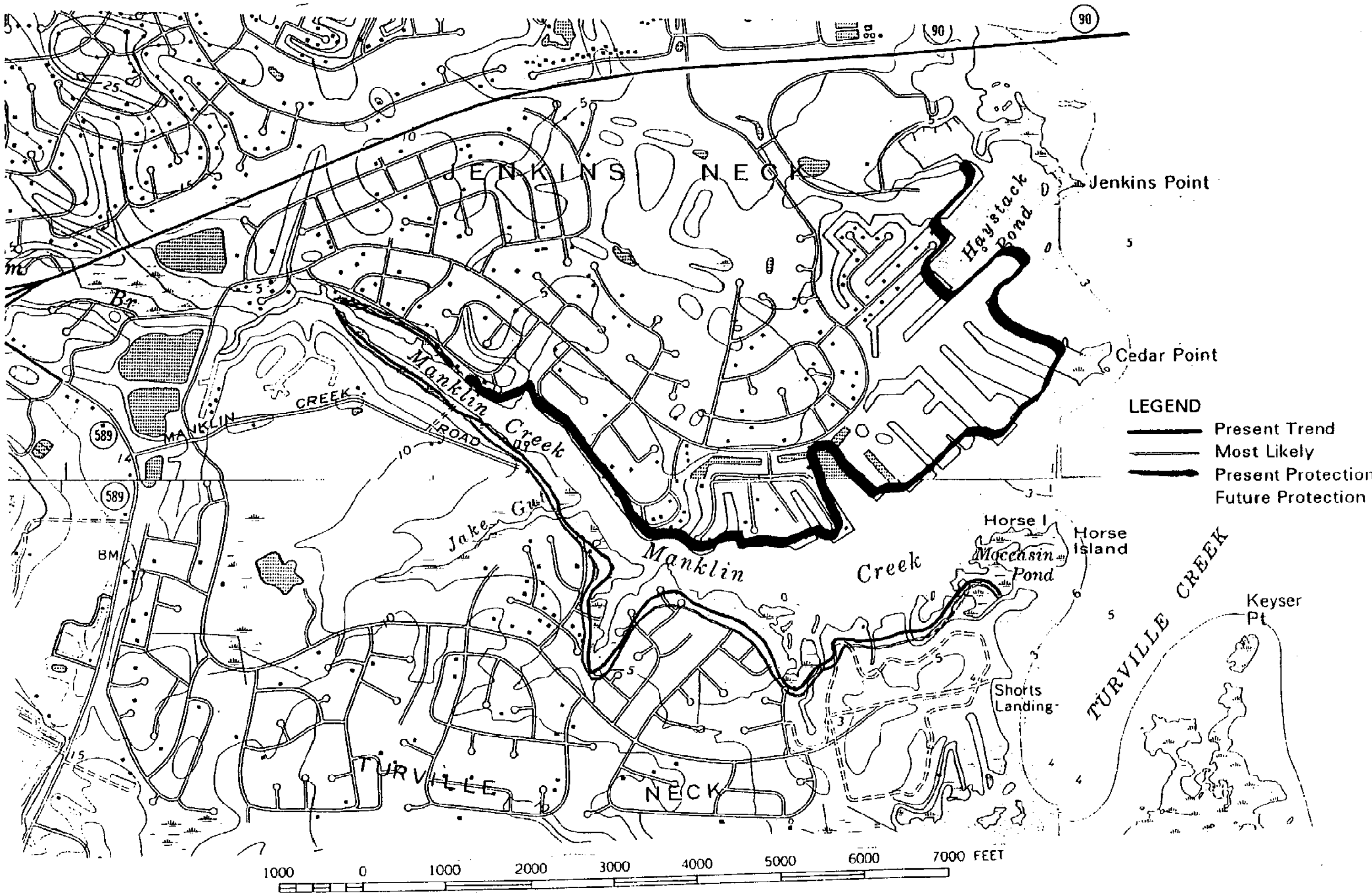

Figure 27. Zone 4: Estimated shoreline positions for the year 2050

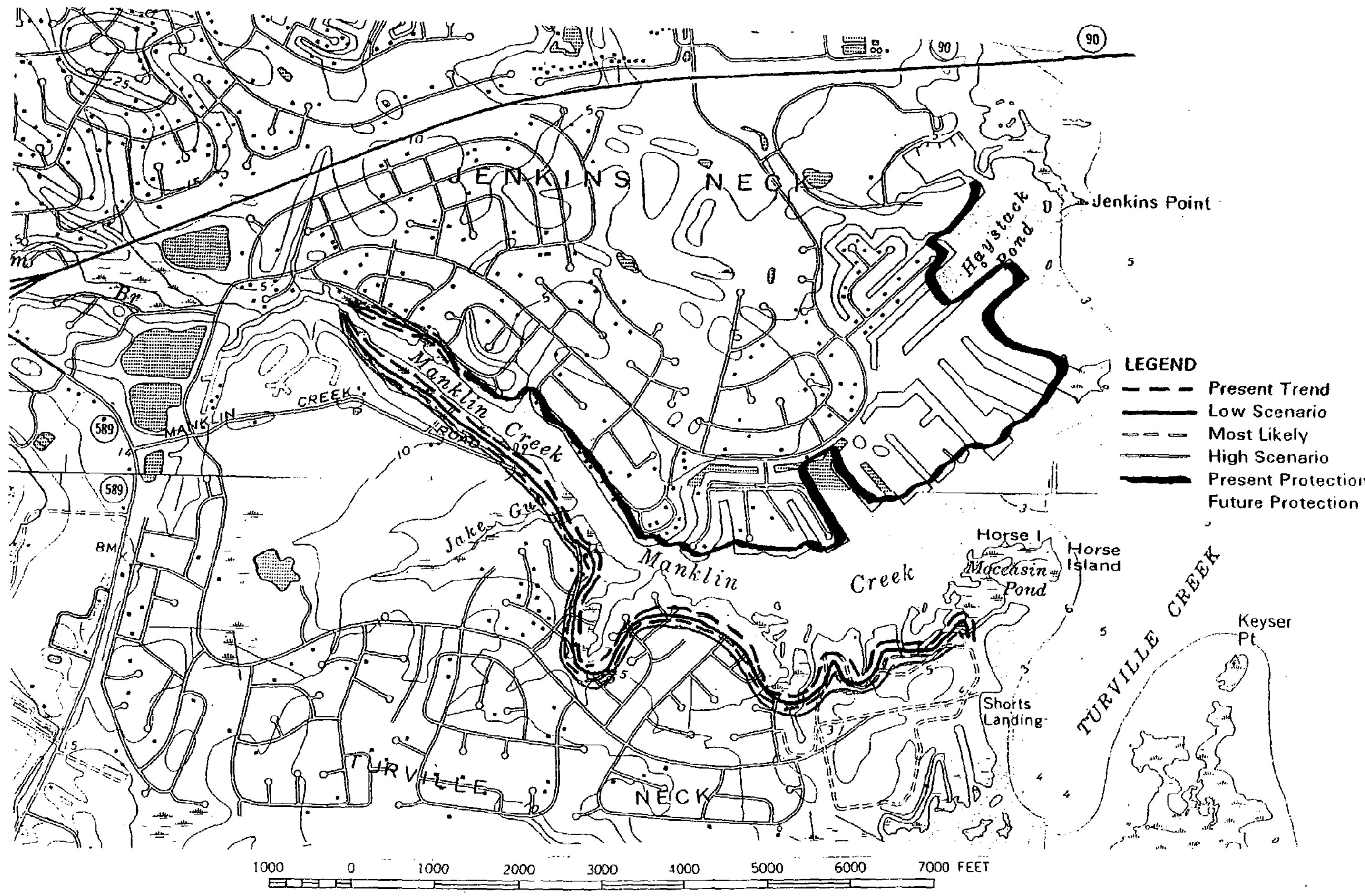

Figure 28. Zone 4: Estimated shoreline positions for the year 2100

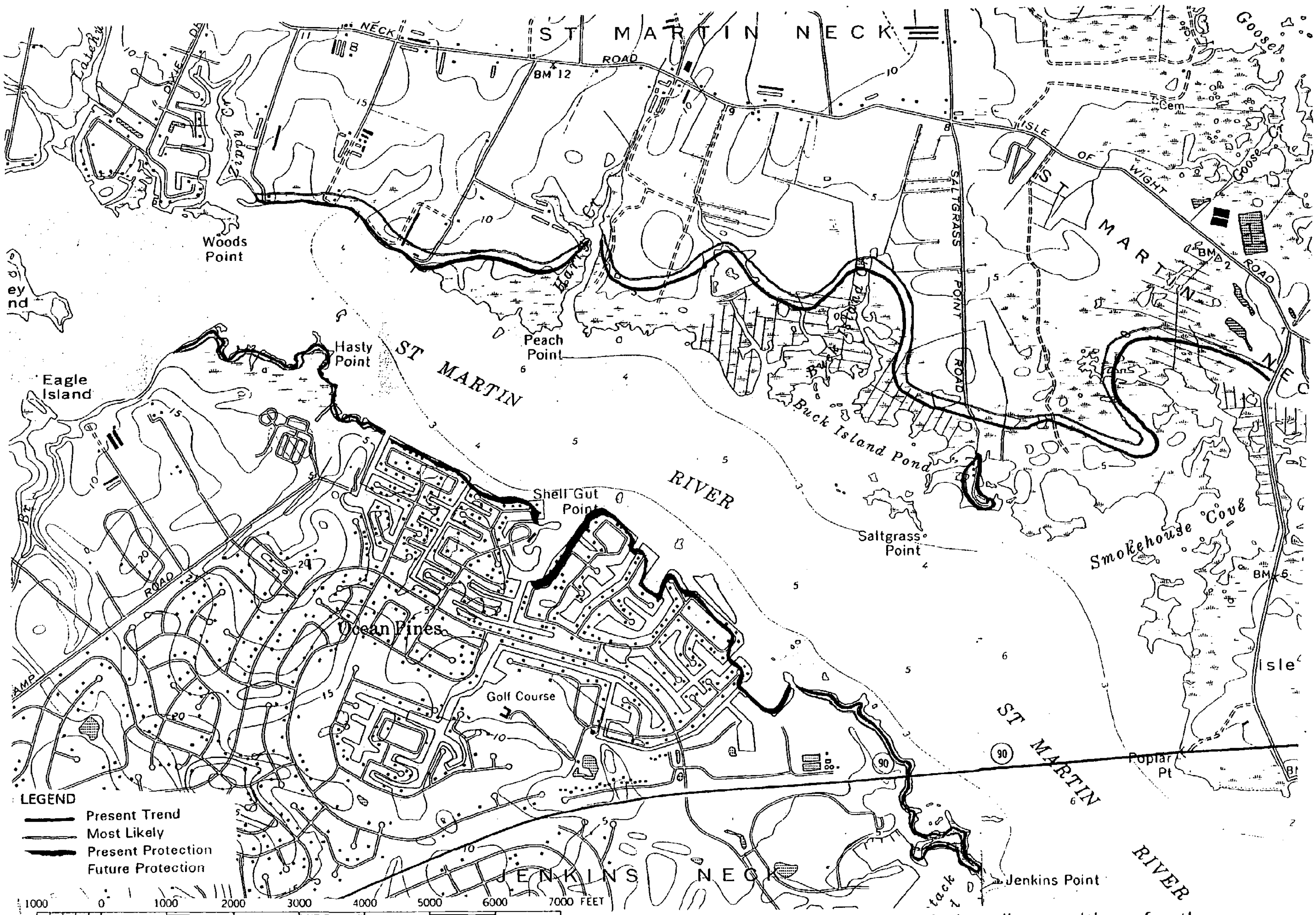

Figure 29. Zone 5: Estimated shoreline positions for the year 2020

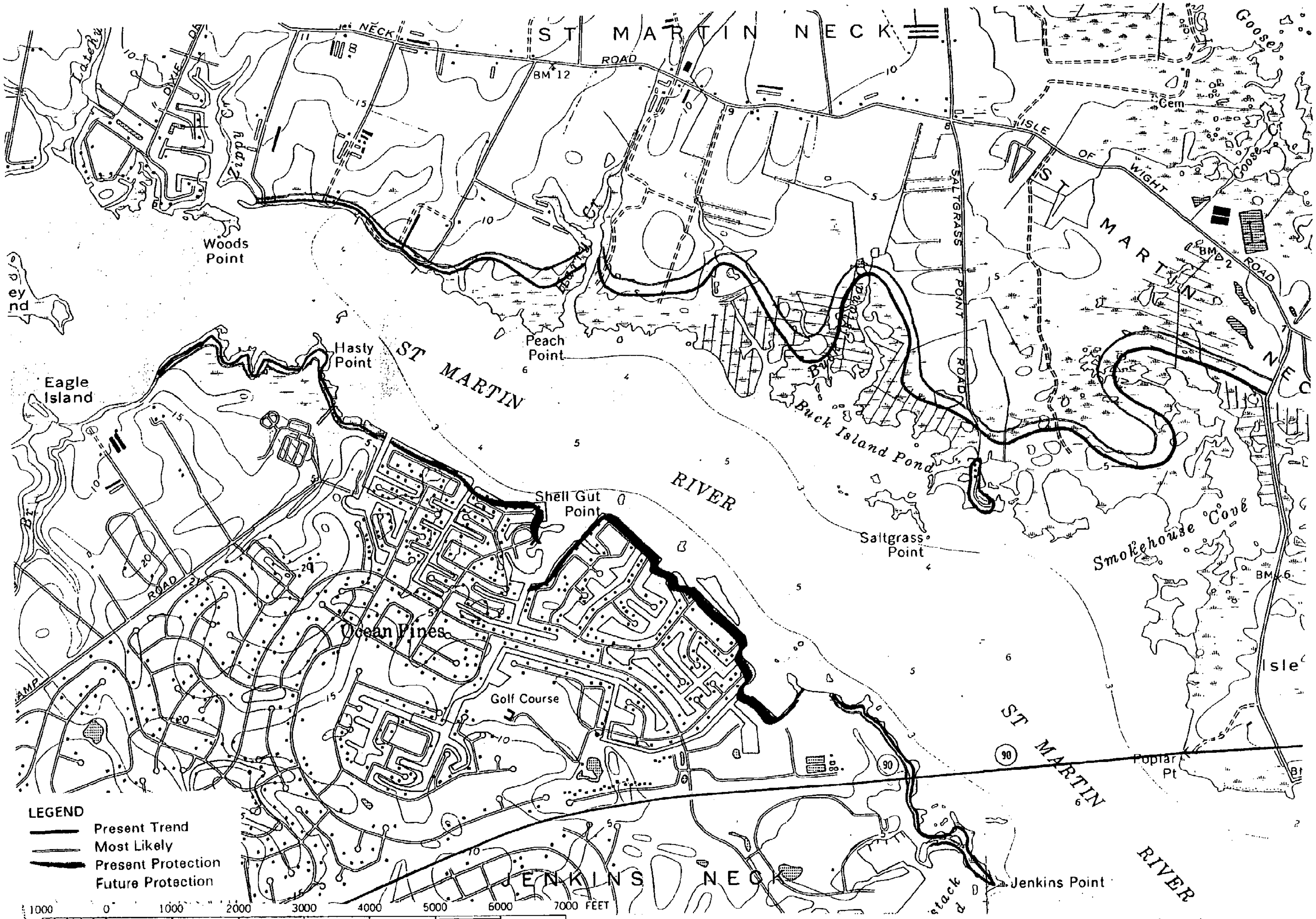

Figure 30. Zone 5: Estimated shoreline positions for the year 2050

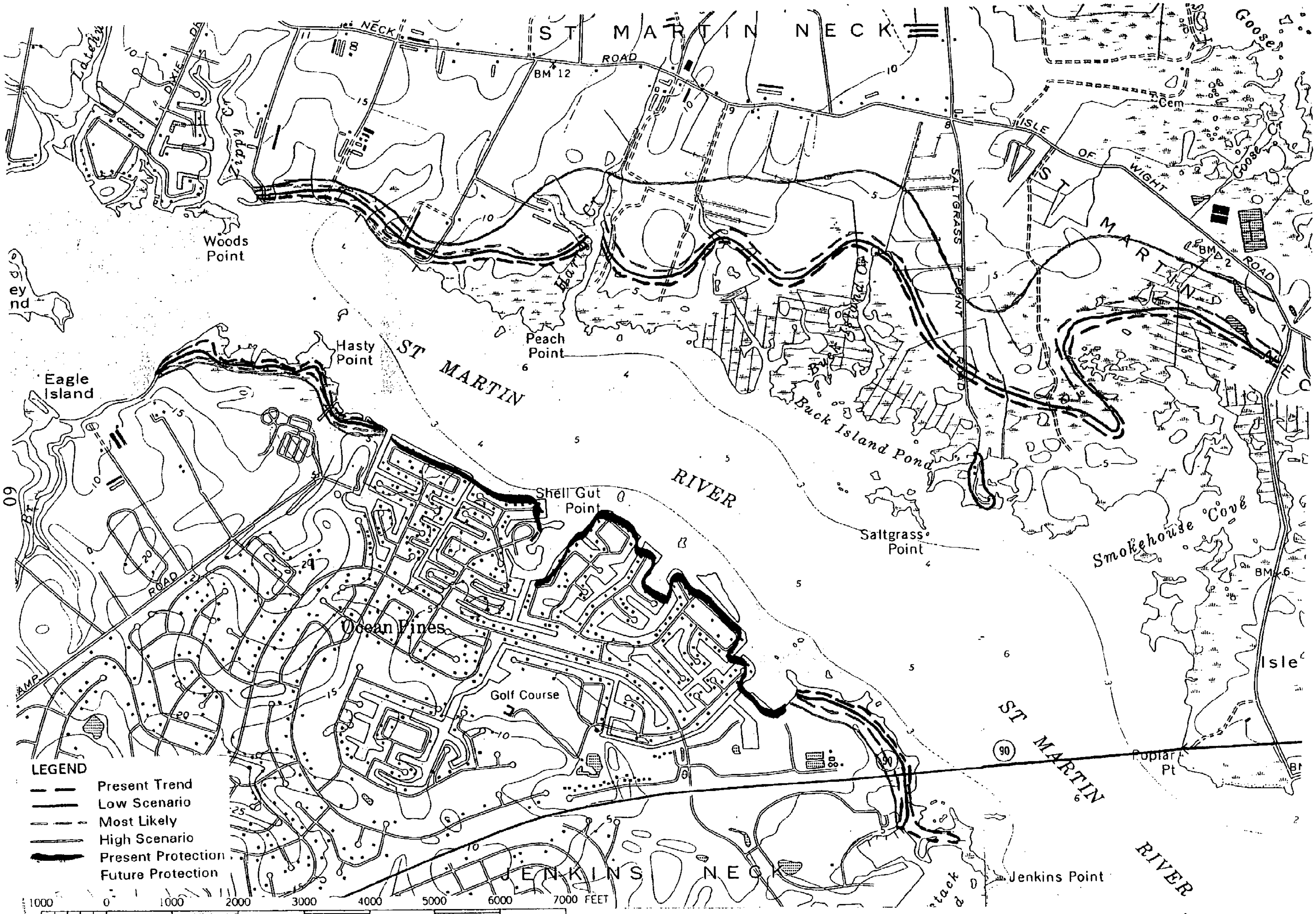

Figure 31. Zone 5: Estimated shoreline positions for the year 2100

Figure 32. Aerial view of St. Martin Neck

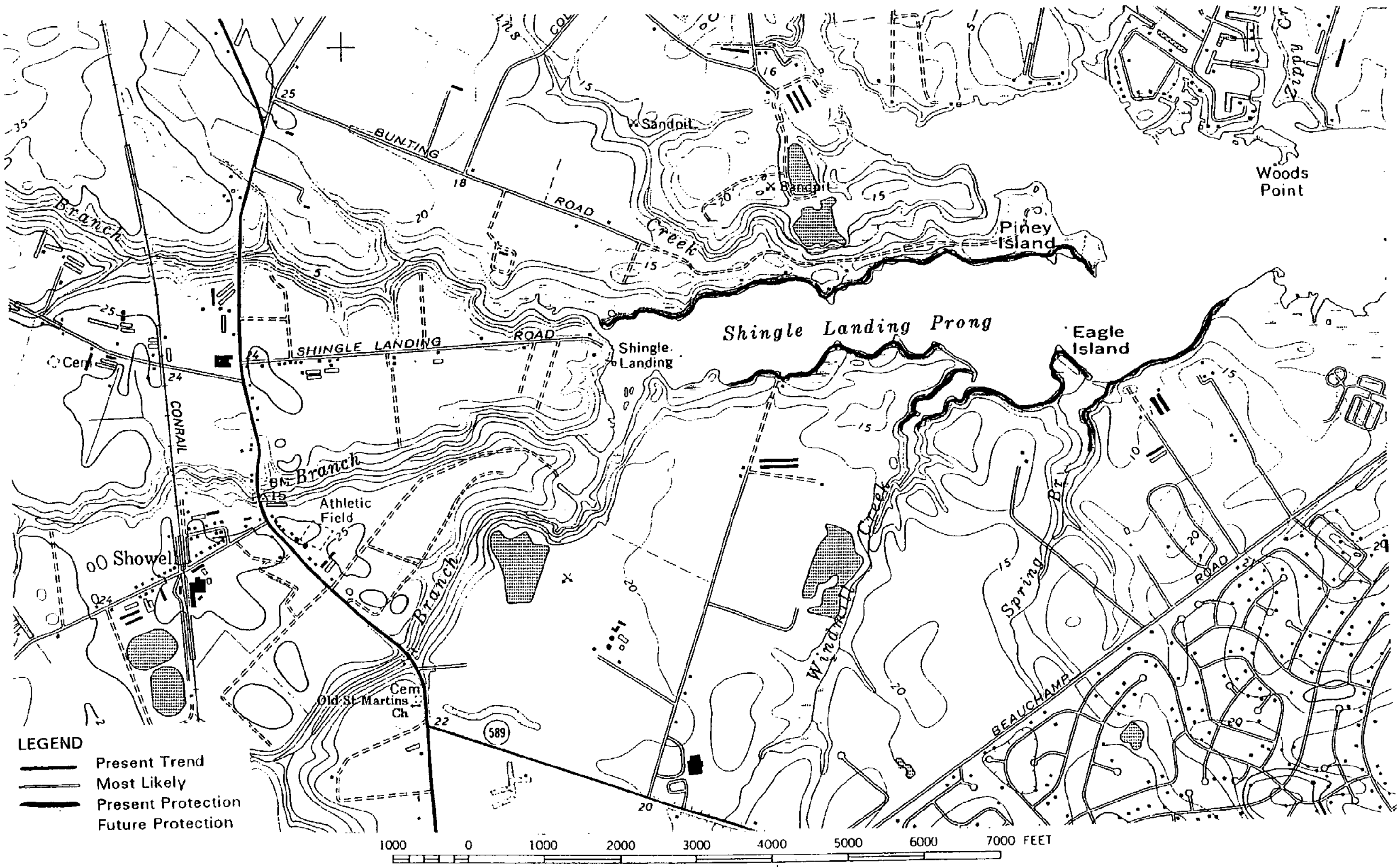

Figure 33. Zone 6: Estimated shoreline positions for the year 2020

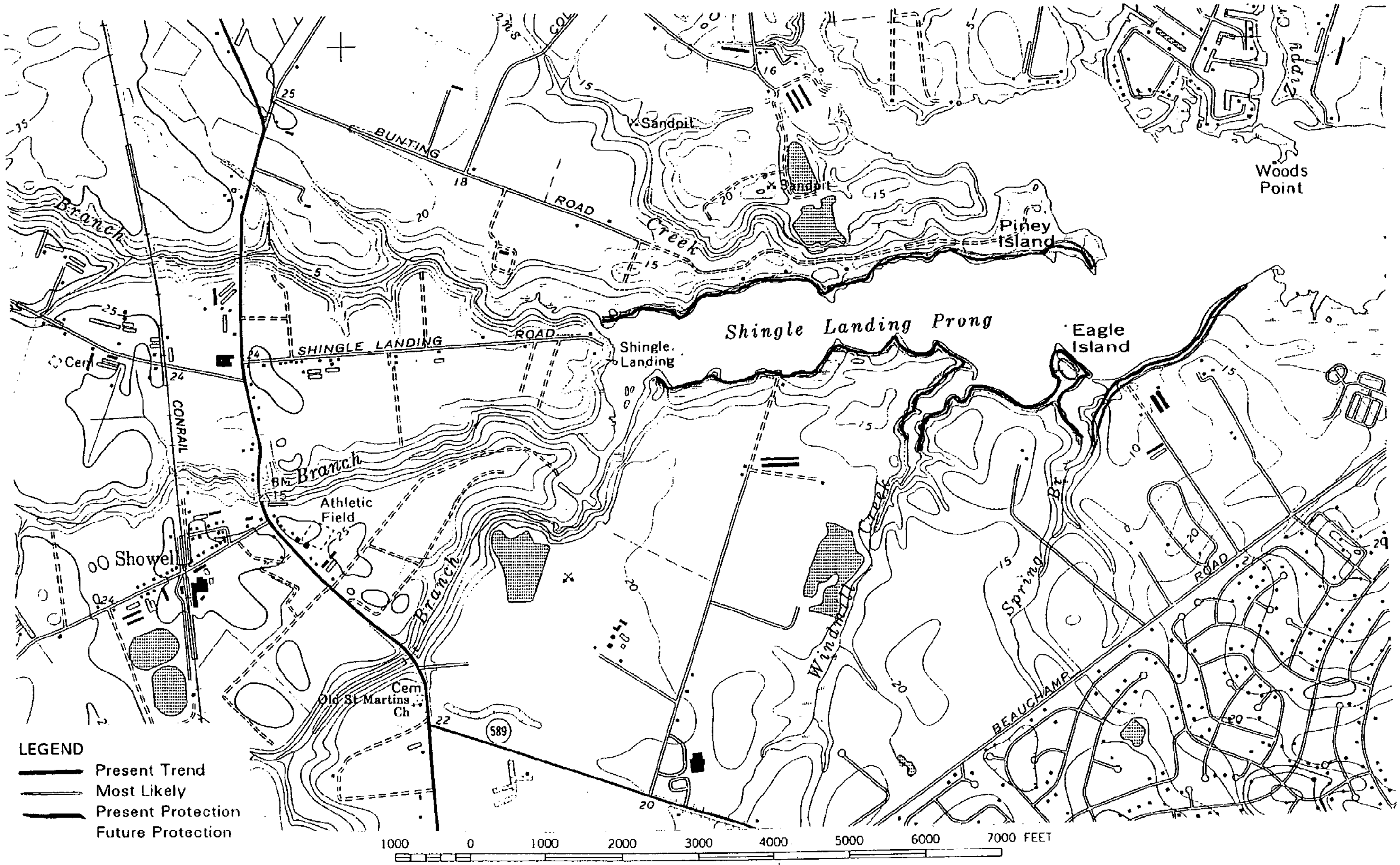

Figure 34. Zone 6: Estimated shoreline positions for the year 2050

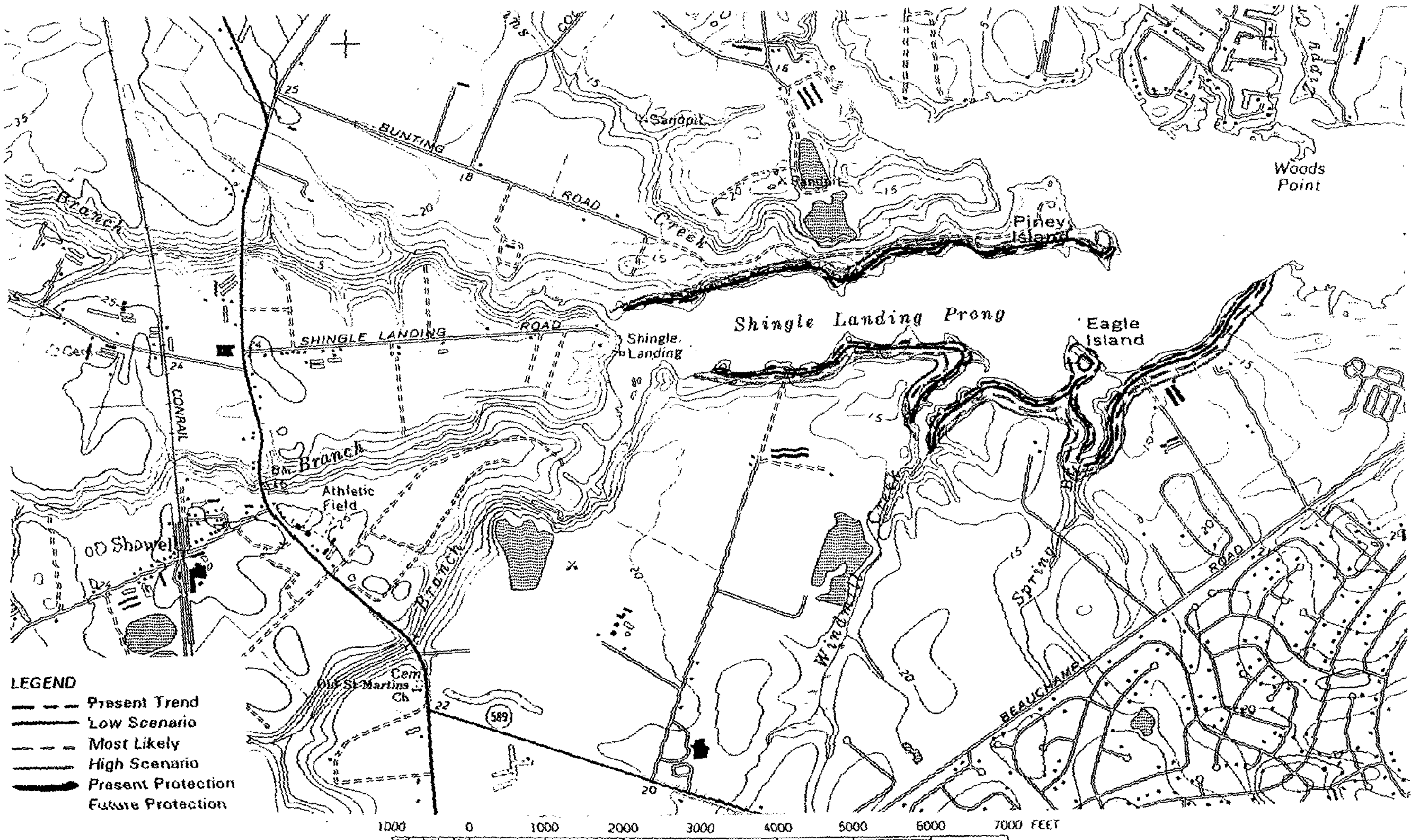

Figure 35. Zone 6: Estimated shoreline positions for the year 2100

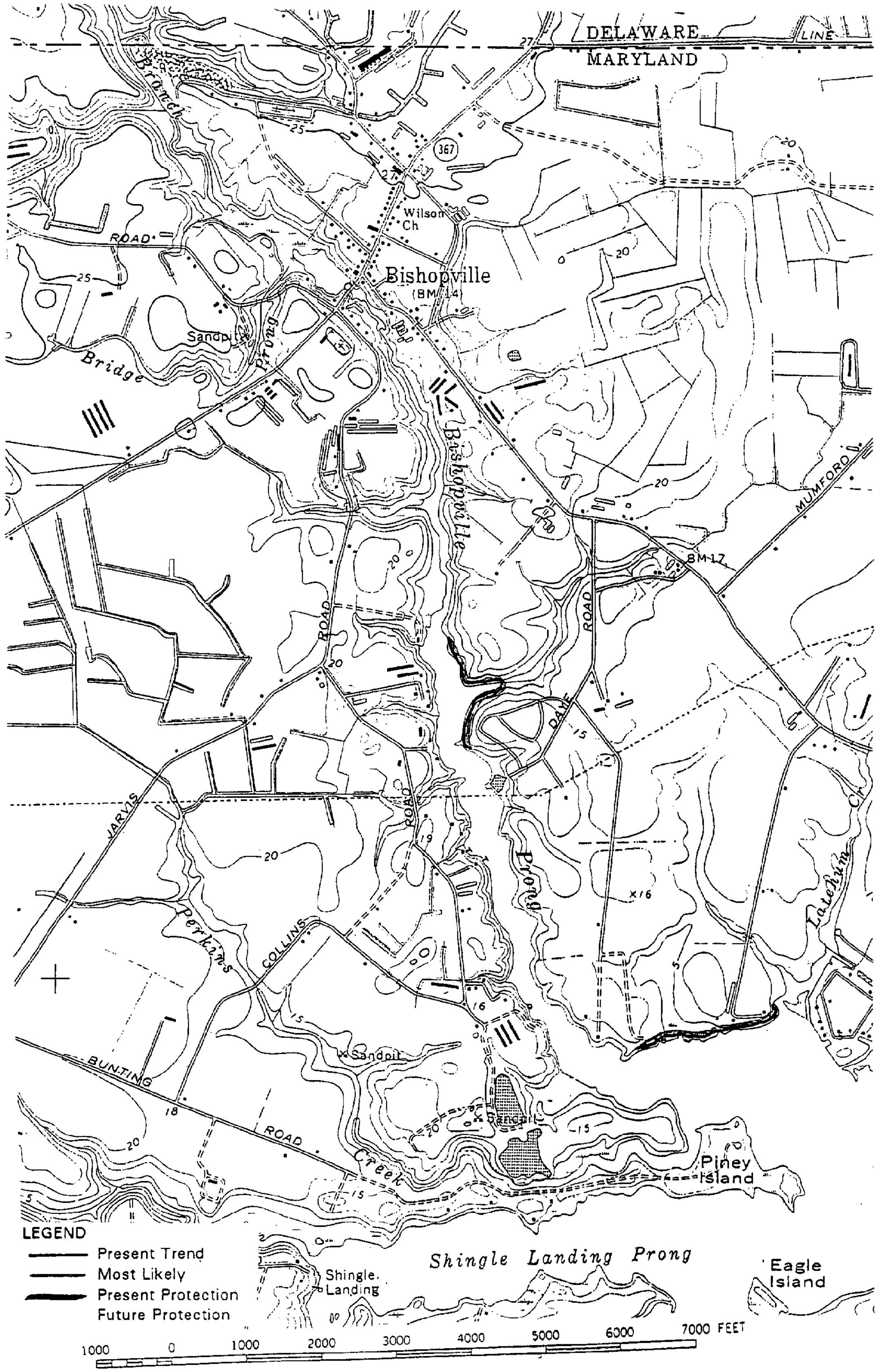

Figure 36. Zone 7: Estimated shoreline positions for the year 2020

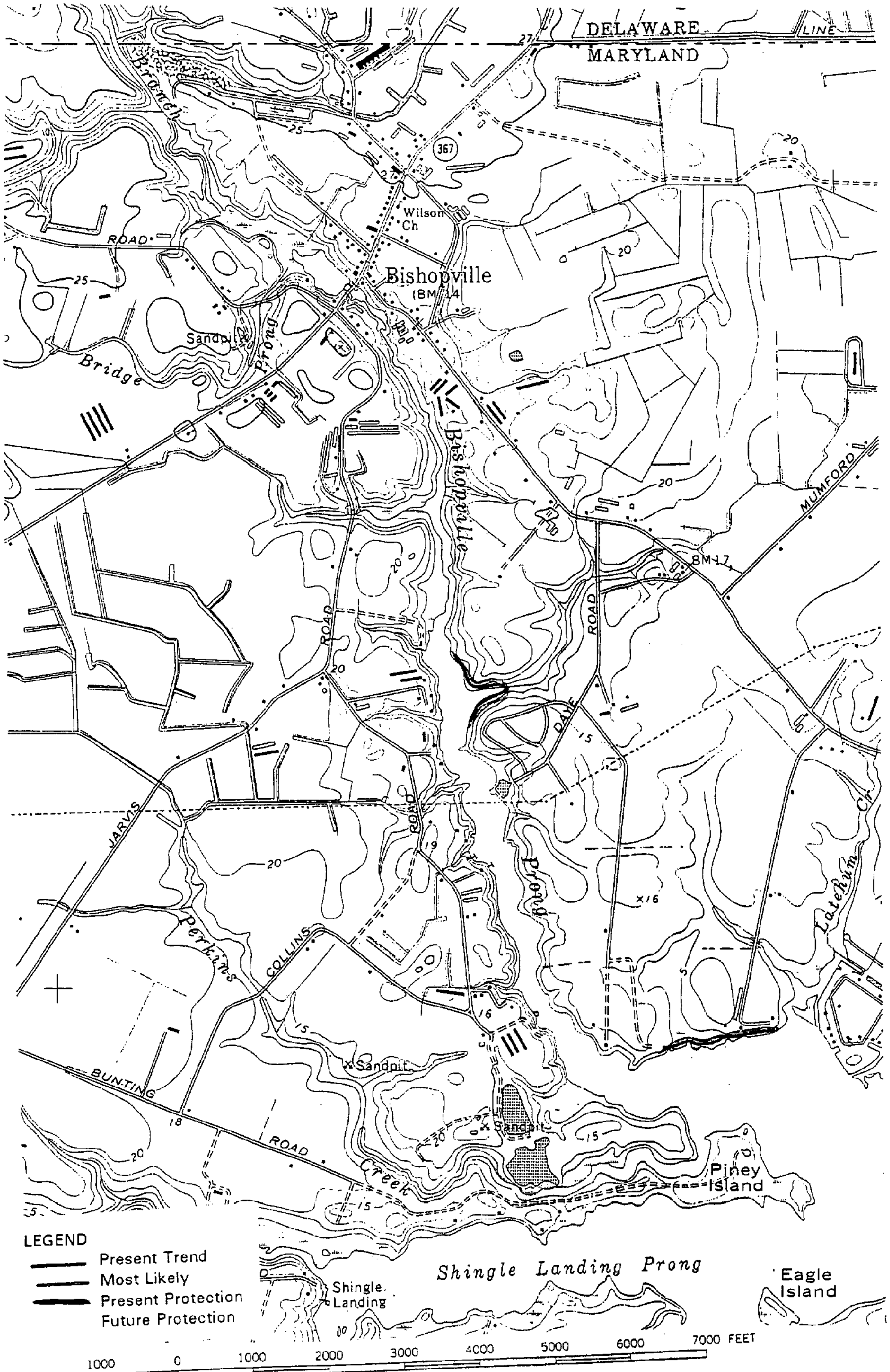

Figure 37. Zone 7: Estimated shoreline positions for the year 2050

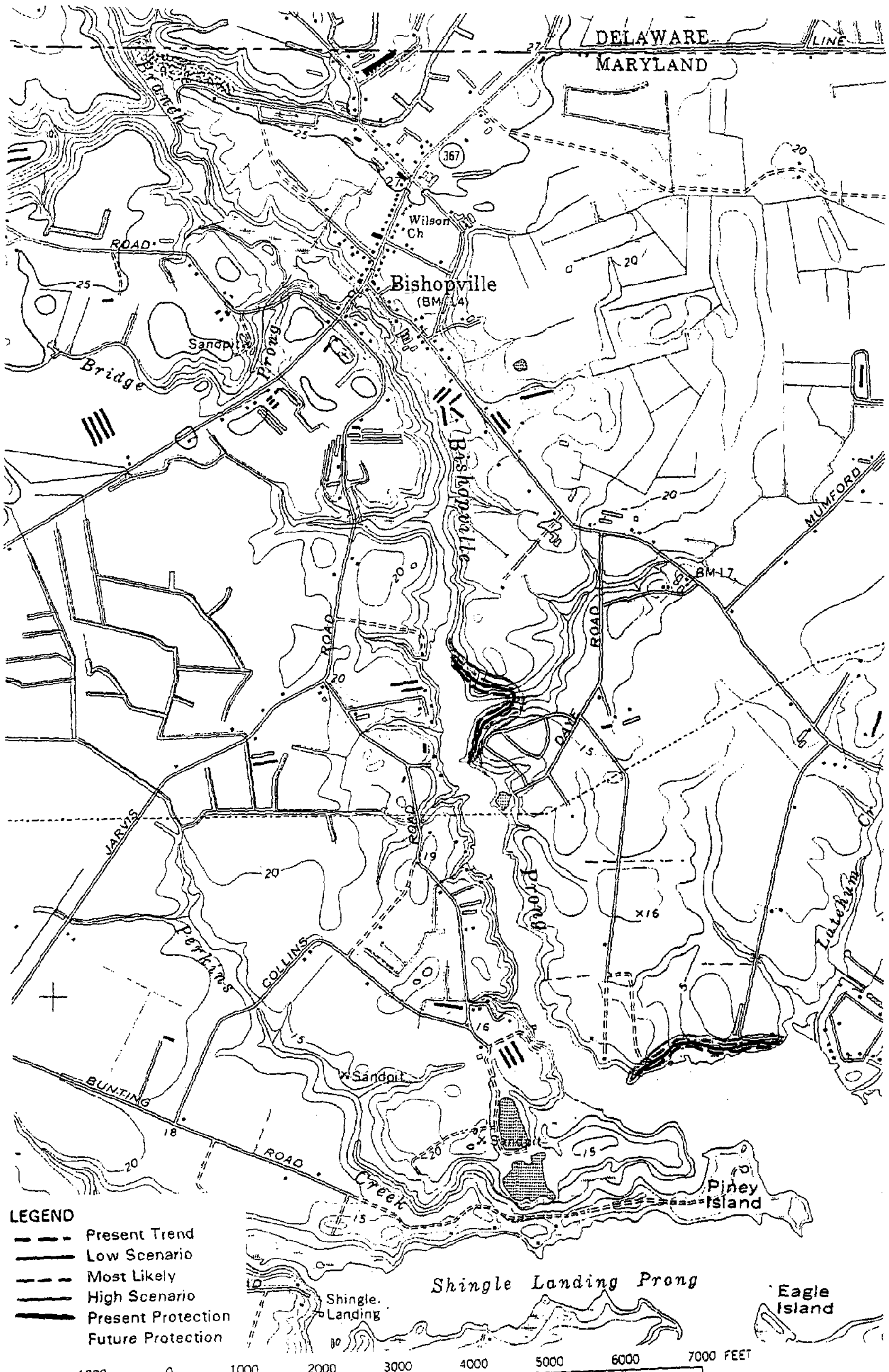

Figure 38. Zone 7: Estimated shoreline positions for the year 2100

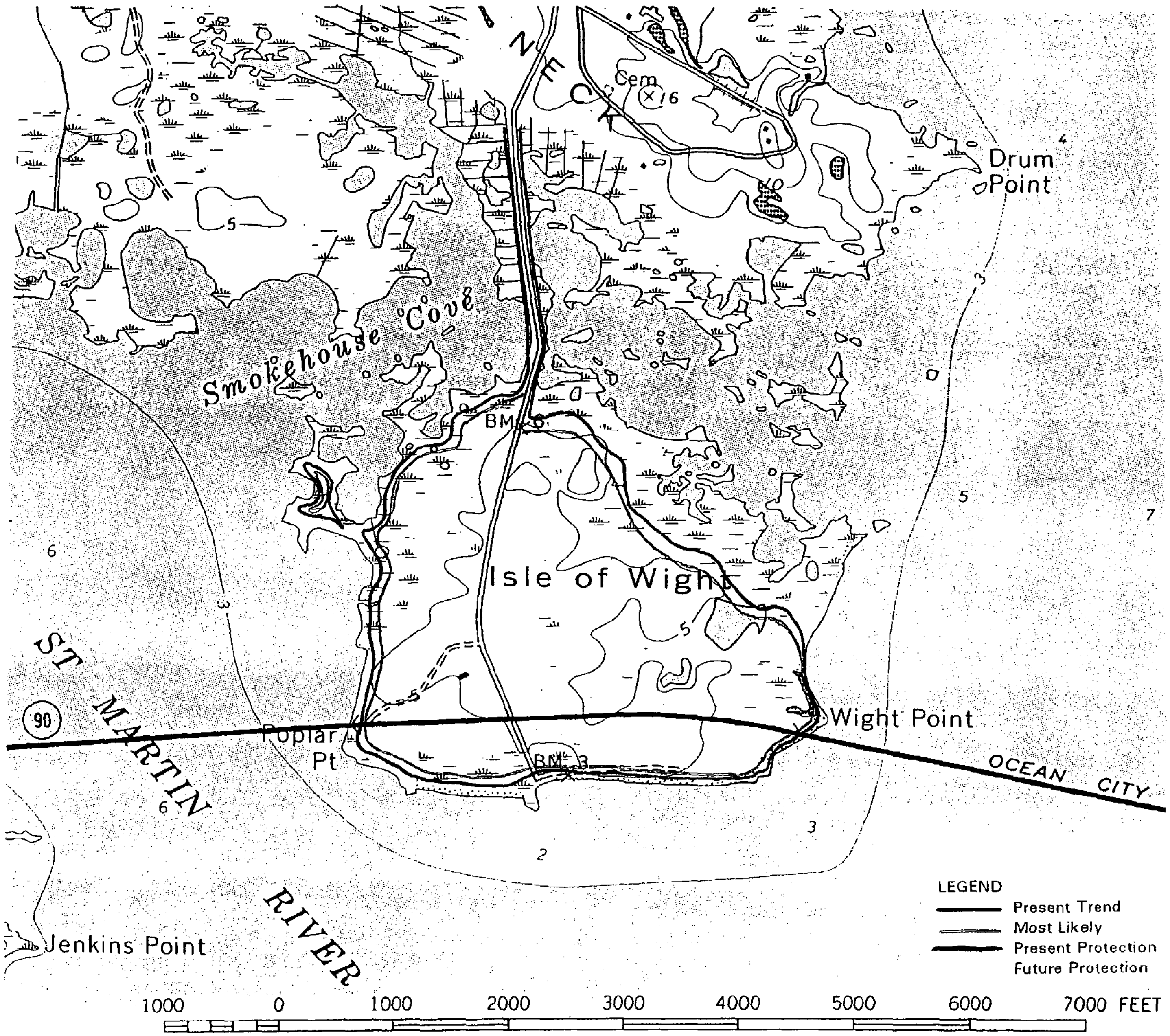

Figure 39. Zone 8: Estimated shoreline positions for the year 2020

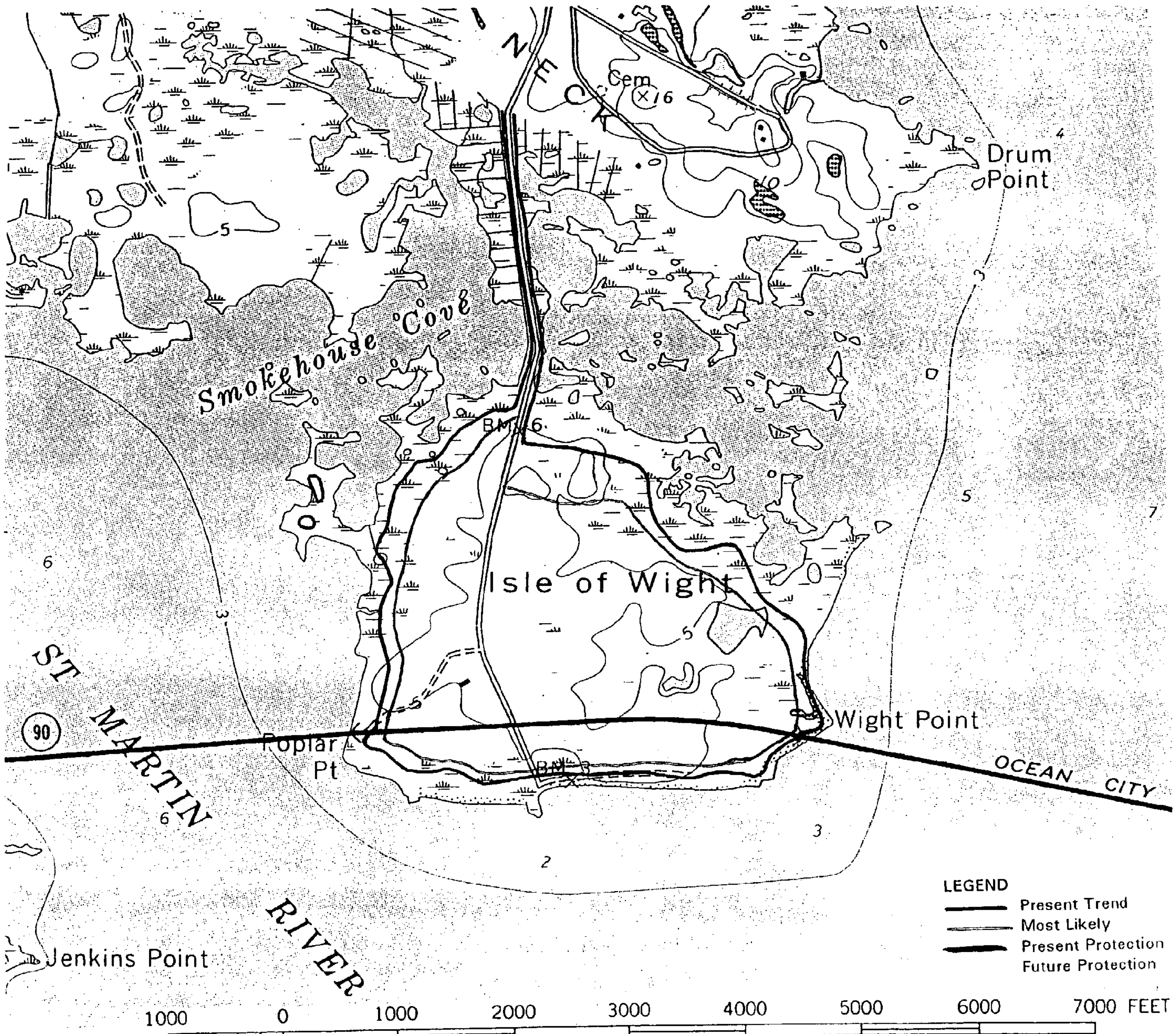

Figure 40. Zone 8: Estimated shoreline positions for the year 2050

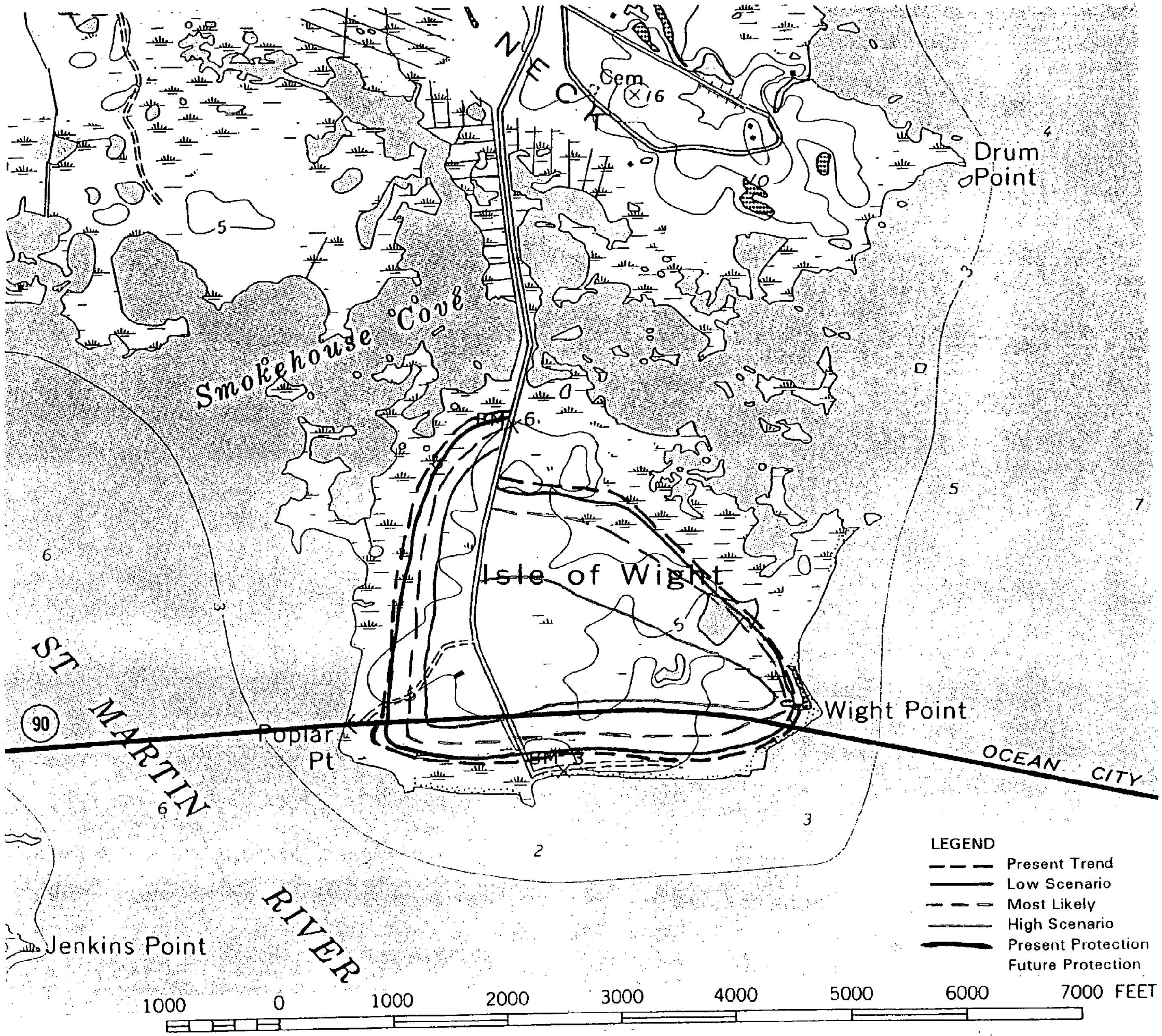

Figure 41. Zone 8: Estimated shoreline positions for the year 2100

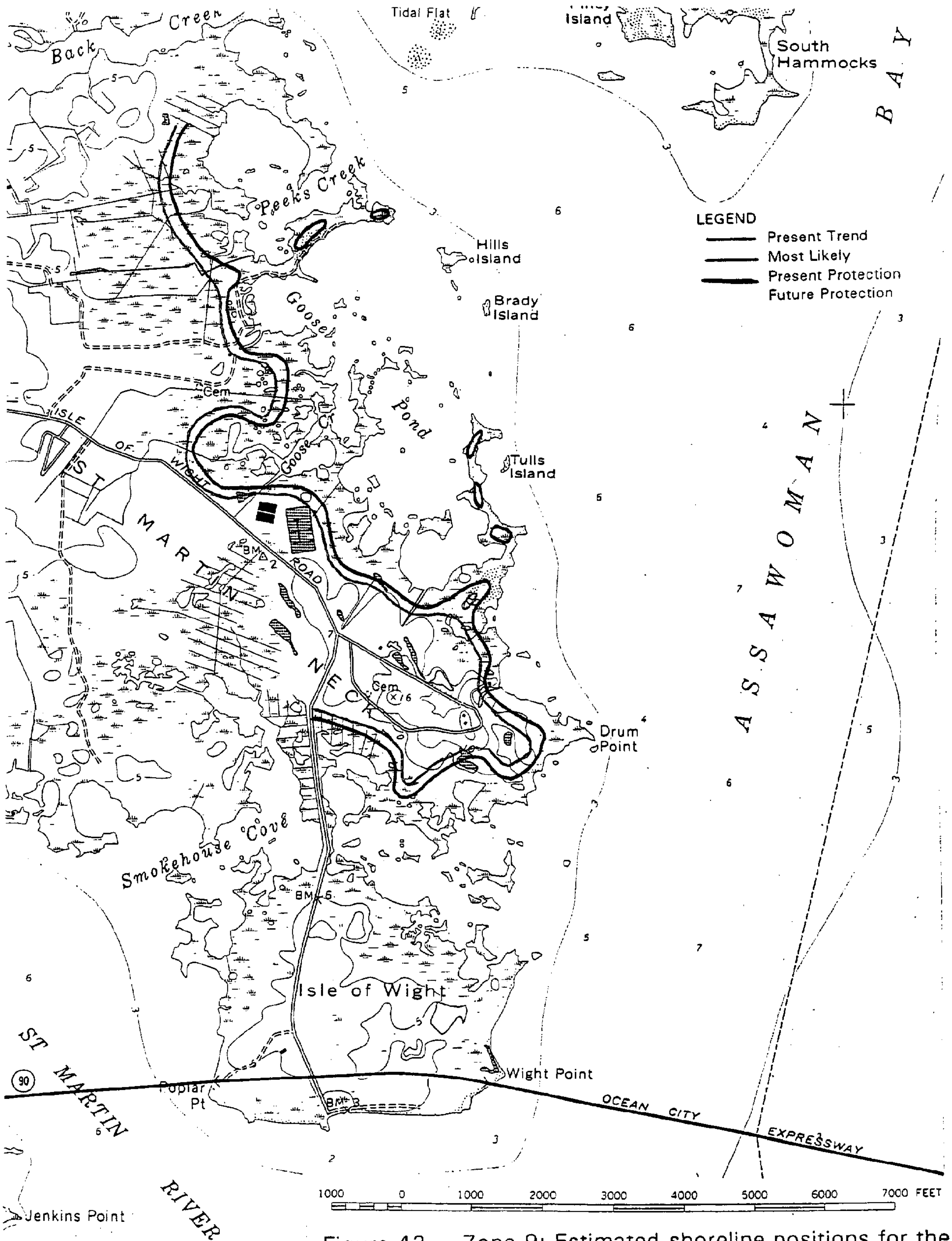

Figure 42. Zone 9: Estimated shoreline positions for the year 2020

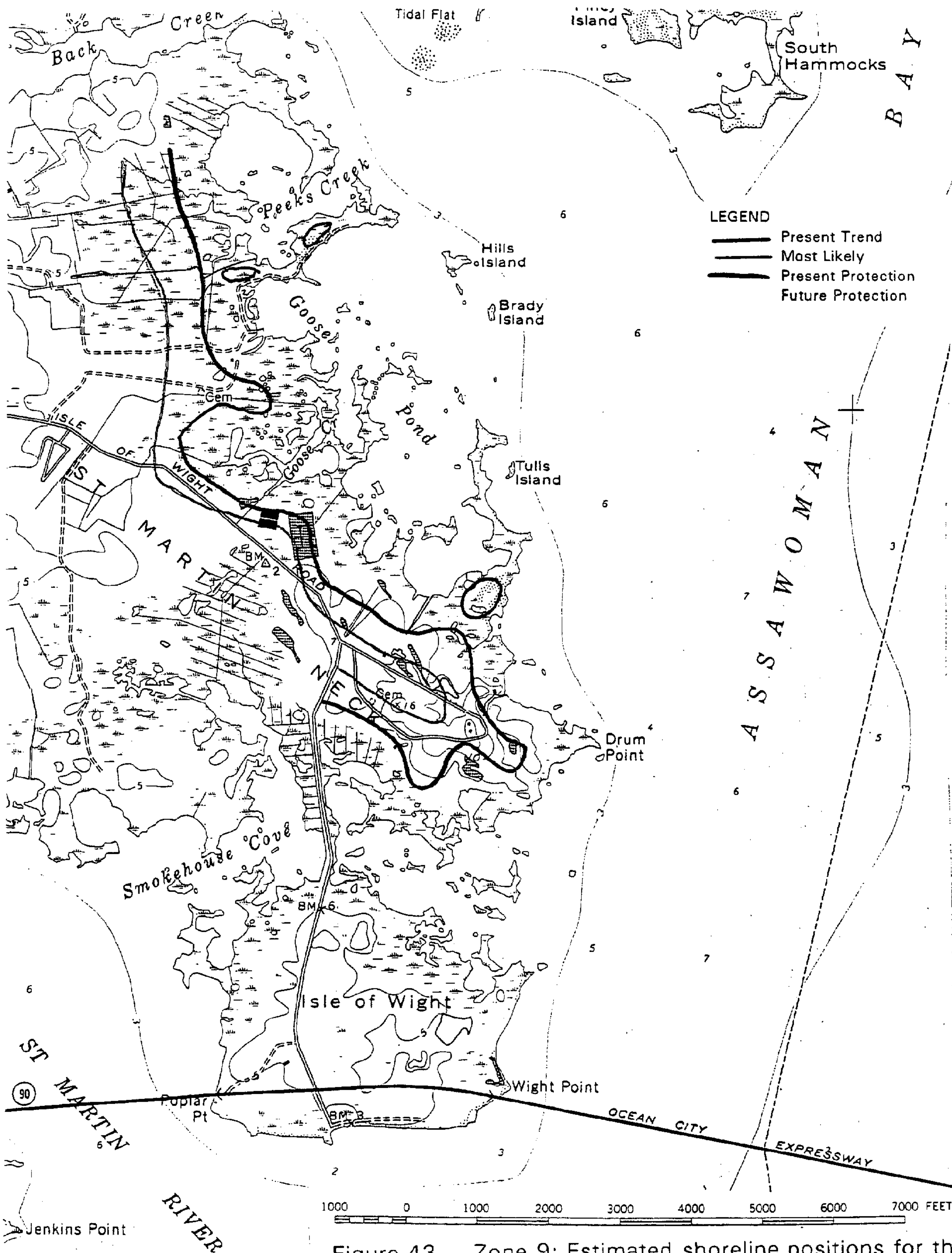

Figure 43. Zone 9: Estimated shoreline positions for the year 2050

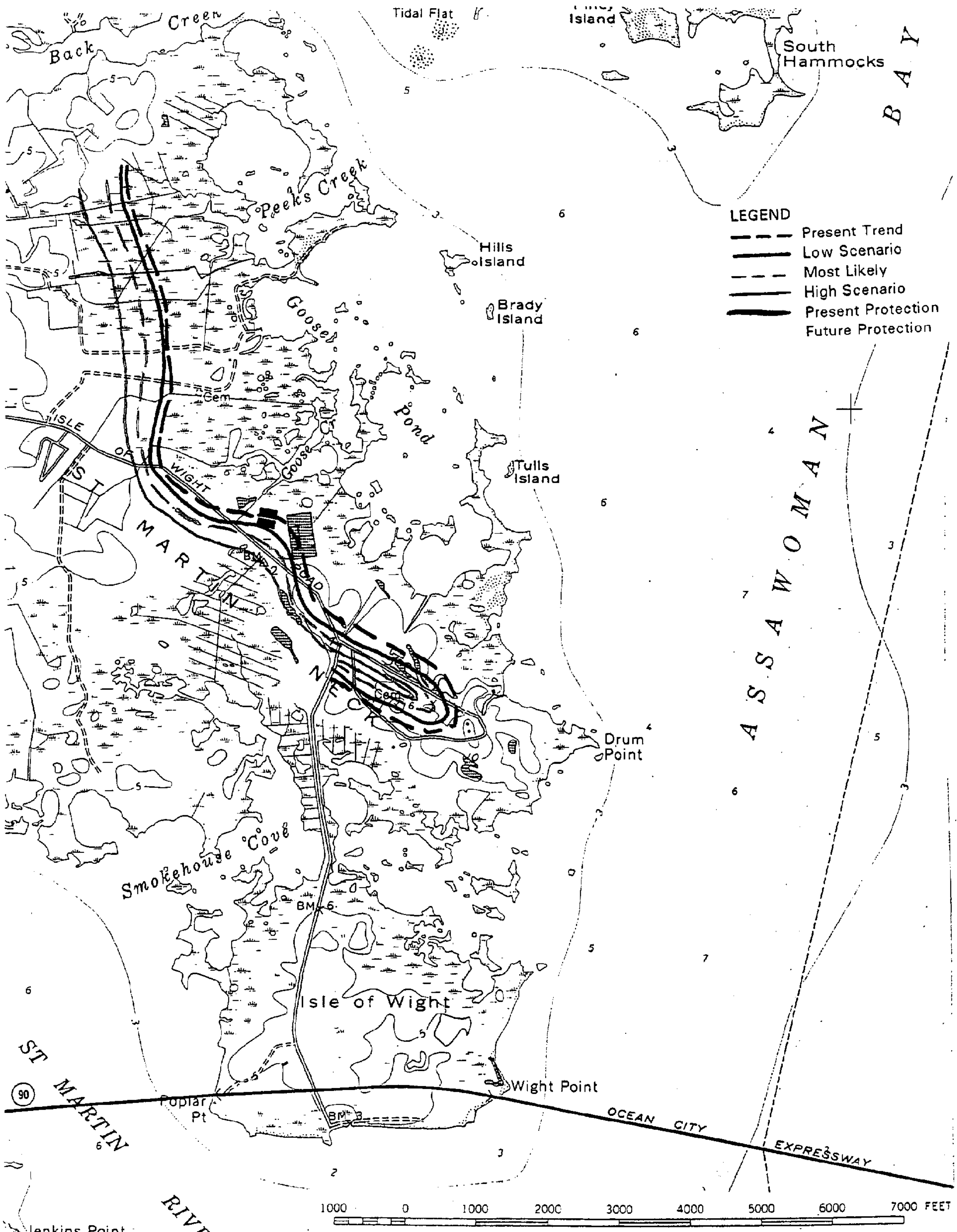

Figure 44. Zone 9: Estimated shoreline positions for the year 2100

Figure 45. Ponding causing wetlands destruction in the Isle of Wight

III. QUANTIFICATION OF LAND AT RISK

After calculating the hypothetical shoreline positions for the various sea level rise scenarios, we were able to estimate the amount of land that could be at risk from erosion and permanent inundation. These estimates were obtained by assuming that existing shoreline protection will be maintained, and that no additional shoreline protection would occur. It was estimated that in 1989 there were about 1500 acres of wetlands in the study area. We estimated that the total existing wetlands could be submerged and eroded by the year 2050 if sea level reaches 1.5 feet above present levels. By the year 2100, all existing wetlands would be destroyed for all sea level rise scenarios.

Table 17 provides quantitative values for the estimates of upland and wetland areas at risk (in acres) for different scenarios of sea level rise. Figure 46 shows a graph of total land at risk under the various sea level rise scenarios. It should be noted that in accordance with the model, present wetlands were not allowed to accrete and, therefore, once they are destroyed, those areas are treated as sandy shores. In a later section we will discuss the possibility of new wetland formation as sea level rises.

Table 17. Land at Risk (acres)

Year	Scenario (ft)	Marsh	Other*	Total
2020	0.4	431	22	454
	0.5	552	30	582
2050	0.8	889	44	933
	1.5	1059	334	1393
2100	1.4	1059	290	1349
	1.7	1059	367	1426
	3.0	1059	673	1732
	4.4	1059	1404	2463

* Other category includes upland areas other than marsh areas.

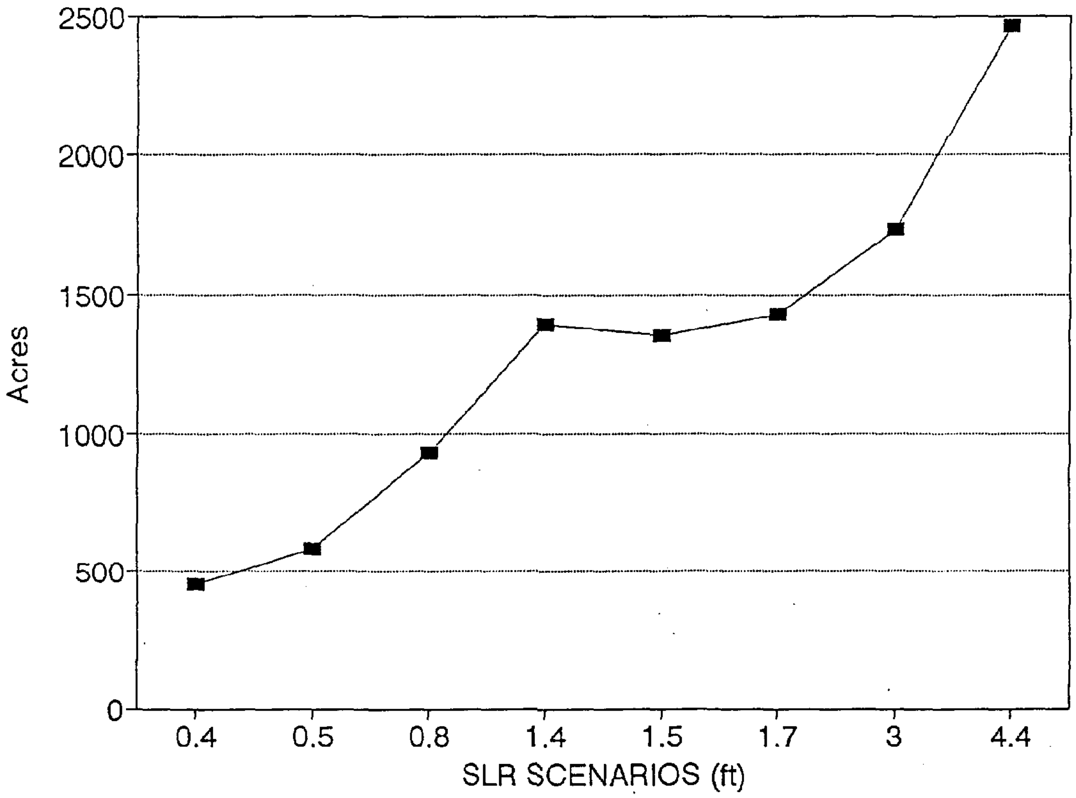

Figure 46. Total land at risk vs. sea-level rise scenarios

In Table 18 we estimated the total acreage of land within each zone at risk from the various sea level rise scenarios. Note that zones 5NB and 9 (Table 18) could have the greatest amount of land at risk due to sea level rise (50 percent of the total land at risk in the study area). These two areas have the most extensive areas of wetlands and the highest historical rates of shore erosion in the study area. As sea level increases, more areas will become vulnerable to inundation and erosion. Zone 8 and 2NB (Table 18) show extensive land at risk for sea level rise scenarios higher than 1.4 feet.

The vulnerability of some of the marsh islands such as Horn, Drum, Dog and Bitch, Horse, Hills and Brady should also be of concern. They all are located on the open waters of both bays and are barely above sea level. Small increases in sea levels could cause them to ultimately disappear. Other islands inside creeks, such as Eagle and Piney Islands could also be reduced significantly. Other geographic features at risk include points, which are remains of some of the older wetland areas such as Keyser, Jenkins, Cedar, and Drum. In addition, tidal flats and shoals, the main sediment supply for the shores of the bays, are at risk due to sea level rise.

Table 18. Land at Risk by Zone (Total Acreage)

	YEARS							
	2020		2050			2100		
	Sea Level Rise Scenarios (ft)							
Zone	0.4	0.5	0.8	1.5	1.4	1.7	3.0	4.4
1	48	66	103	168	165	182	223	283
2SB	28	37	58	91	88	93	105	148
2NB	31	39	64	96	95	101	120	189
3EB	21	27	44	61	59	62	68	79
3WB	17	22	34	57	55	57	62	70
4SB	16	19	31	46	44	45	64	160
4NB	4	5	7	7	6	6	8	16
5SB	7	8	12	20	18	20	33	45
5NB	120	144	228	282	278	286	324	548
6SB	7	8	10	14	14	16	29	40
6NB	3	3	5	9	9	11	23	32
7WB	0	0	0	0	0	0	0	0
7EB	1	5	8	15	14	16	25	37
8	41	50	80	131	120	131	172	260
9	111	149	250	396	385	401	475	557
TOTAL	454	582	933	1393	1349	1426	1732	2463

Notes:
NB: North Bank of Zone
SB: South Bank of Zone
EB: East Bank of Zone
WB: West Bank of Zone

SUMMARY

- Inundation is about 60 to 80 percent of the total future shoreline recession in our study area, and is a much more important problem than erosion.

- Wetlands are more vulnerable to sea level rise than sandy shores and creek banks because of their low-lying elevation.

- Creeks banks will experience the greatest shoreline retreat at their mouths.

- St. Martin Neck could be breached by sea level rise scenarios greater than 1.4 feet, forming an island north of Isle of Wight.

- Shingle Landing and Bishopville Prong are the least vulnerable to erosion and inundation mainly because of their steep slopes and absence of wetlands.

- Many of the present natural shoreline features are threatened by erosion and inundation and could disappear, including islands, points, and tidal flats.

- The north bank of St. Martin River and the shores of the Assawoman Bay are the most vulnerable shorelines and have the greatest amount of land at risk for all sea level rise scenarios. For the higher scenarios (1.4 feet and greater), Turville Creek (north bank) and Isle of Wight are most vulnerable.

- About 50% of the total land of Isle of Wight is at risk of erosion and permanent inundation.

CHAPTER FIVE
IMPACTS

I. LAND AT RISK

According to the Worcester County Comprehensive Development Plan, six land use types exist in the study area (Figure 13). In this section we compare the land use categories at risk from the various sea level rise scenarios. Table 19 summarizes the total land at risk for each land use type under future sea level rise scenarios.

We measured the 1989 shoreline for each of the land use types and found that 58 percent of the study shoreline has been designated Suburban Residential land use. We also found that between 60 and 70 percent of the total upland at risk in this study area is the Suburban Residential land use type. Suburban residential land use exists in the entire study area except in Zones 6, 7 and 8 (Figure 3). According to the Worcester County Comprehensive Development Plan (CDP, 1989), this category of land use has been designated to accommodate a large portion of the future growth of the county's population. We believe that the inundation of low-lying areas will cause a greater impact on the study area shorelines than shore erosion alone.

Table 19. Land at Risk by Land Use (Acres)

	YEAR							
	2020		2050			2100		
	Sea Level Rise							
LAND USE	0.4	0.5	0.8	1.5	1.4	1.7	3.0	4.4
Commercial	7	10	17	29	28	31	40	53
Suburban Residential	268	354	576	890	873	920	1093	1460
Suburban	0	0	0	0	0	0	1	1
Estate	137	166	259	318	315	323	366	405
Agriculture	0	0	0	0	0	1	1	1
Conservation	41	50	80	131	120	131	172	260
TOTAL	454	581	933	1368	1337	1405	1673	2180

The Rural Estate land use comprises between 20 and 30 percent of the total land at risk in our study area (Figure 13). Low density residential homes with large open spaces and environmentally sensitive areas occur in this land use type. Rural Estate land use occurs in zones 5, 6 and 7 (Figure 3 and 13) predominantly on the north bank of the St. Martin River, where the greatest shoreline recession is projected.

The Commercial land use type occurs in zones 1 and 3 along Route 50 (Figure 3 and 13). This land use type accounts for only 3.5 percent of the entire shoreline under study. The amount of land at risk under this type ranges from 7 to 53 acres.

Only a small portion of Suburban and agricultural land use types are located on the study area (banks of Herring Creek, zone 3, Figure 3 and 13). The amount of land at risk under these two categories ranges from 0.2 to 1.4 acres.

Finally, the Isle of Wight is classified under the conservation land use type (Figure 13). Close to 50 percent of the entire island or 260 acres, could be at risk under the highest sea level rise scenario of 4.4 feet.

II. ECONOMIC AND INFRASTRUCTURE AT RISK

Presently, the recreational and resort-related industries employ about 61 percent of the residents of Worcester County (CDP, 1989). The primary tourist attraction in the county is the Atlantic Ocean shoreline. However, the back bays also attract many tourists. Sea level rise could impact the economy of the County in this area by eroding and inundating land areas.

One of the possible strategies to protect the economic activities and infrastructure of the area is to invest in engineering structures, such as stone, breakwaters or bulkheads. However, these structures are expensive and can be detrimental to the environment. Wetland creation and beach nourishment are less costly engineering options and are not normally detrimental to the environment.

Routes 50 and 90 are the major transportation links between Ocean City and the mainland. Both routes are at risk from sea level rise, through; (1) erosion which can undermine foundations of bridges or shoulders of the roads and; (2) flooding which affects low-lying areas. Route 50 is most vulnerable at Herring Creek and near West Ocean City. Route 90 could be impacted near Ocean Pines and on Isle of Wight. The entire length of Route 90 on the Isle of Wight is located on grounds under 5 feet above present sea level. It was projected that the southern shore of the island would retreat as much as 600 feet in response to a 4.4 feet sea level rise.

III. WETLAND LOSS

Land loss in most marshes results from a combination of two mechanisms; *shore erosion and inundation* (Leatherman, 1989; Gehrels and Leatherman, 1989; Orson et al., 1985). Shore erosion at the seaward edge of the marsh is the most obvious process and will accelerate with increased water levels. However, as described previously, erosion accounts for only a small percentage of all marsh losses annually. The comparative resistance of marshy shorelines to wave attack suggests that with rapidly rising sea levels, most marshes will be inundated before extensive shoreline erosion occurs.

A more probable catastrophic mechanism of marsh loss with a large increase in sea level will be the formation of extensive interior ponds. The rapid enlargement and coalescence of interior ponds in marshes subject to rapid coastal submergence have been amply documented in the Mississippi delta (Delaune et al., 1983) and at the Blackwater Wildlife Refuge, Maryland (Stevenson et al., 1986). The physiological mechanism behind the development of interior ponds is believed to be anoxia and ultimate death of marsh plants as sea levels outpace the ability of the marsh to maintain elevation.

As we discussed in previous sections of this study, wetlands have been decreasing since the 1850's. The rates of retreat along marshy shorelines were found to be up to 3 feet per year in the most extreme cases. We attempted to determine how erosion and inundation at a marshy shoreline would reduce wetlands with accelerated sea level rise. We also estimated the area of land that could be converted into wetlands due to higher water levels.

Our analysis of existing wetlands in the study area indicates that the entire 1500 acres could disappear completely in response to a sea level rise of 1.4 feet or greater. This sea level scenario is the Best Estimate scenario for the year 2050 and the low scenario for the year 2100 (Table 1). Figure 47 shows a graph of marsh loss vs. sea level rise in our study area. When we compare existing wetlands areas with losses that could occur in the future due to sea level rise, we observe that for the year 2020, 40 to 50 percent of wetlands could be lost. For the year 2050 the losses could range from 84 to 100 percent of today's wetlands. The high water levels projected for the year 2100 could destroyed all existing wetlands for all scenarios. The basis for these results is due to the shore topography of the study area. The slope of these shores is too steep between the 1 and 3 feet elevation contours for the wetlands to migrate upland or for new ones to form as sea level rises.

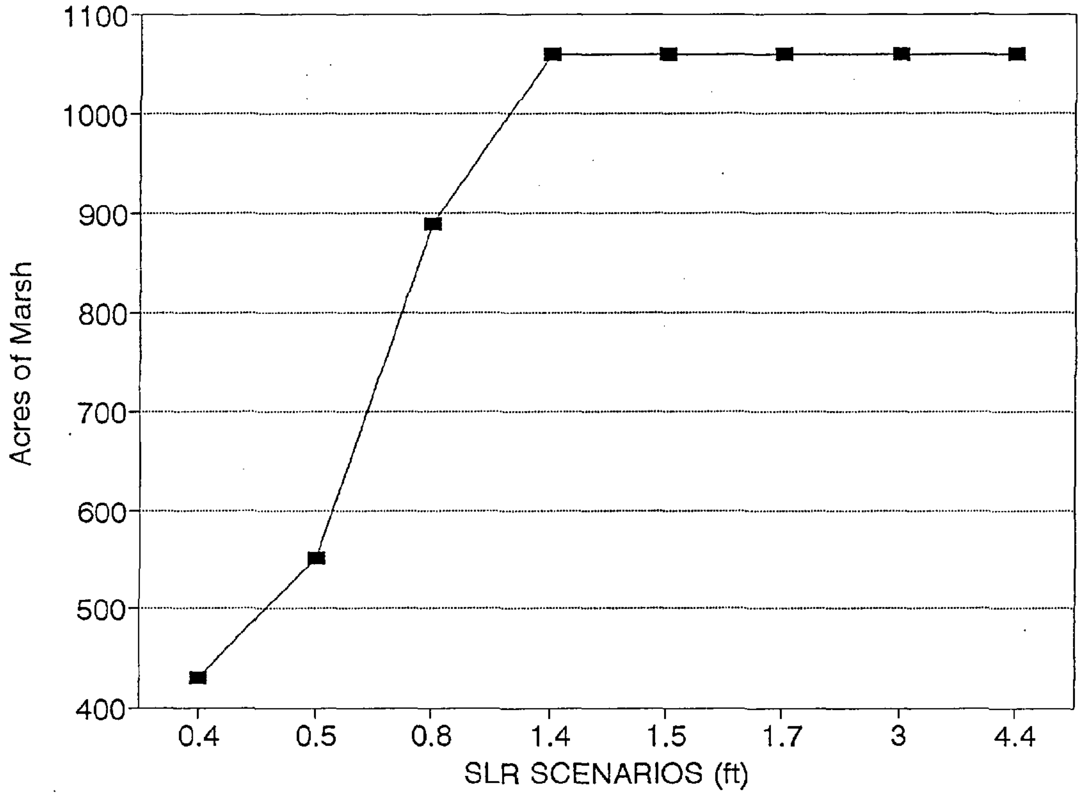

Figure 47. Marsh at risk vs. sea-level rise scenarios

Even though the topography of the study shoreline does not allow for extensive wetlands migration, higher sea levels will affect dry upland areas. The various sea level scenarios were superimposed on the representative shoreline profiles to estimate how much land could be regularly flooding in the future. In this way we determined the acreage of new marshes that could be formed. Table 20 presents a comparison of existing marshes, marsh loss, and the area flooded by higher water levels. It also shows the difference between existing marshes and new marshes, estimating the possible deficit of marshes in the future compared to 1989 acreage.

Table 20. Marsh Loss and Deficit from Existing Marsh
(Acres)

YEAR SCENARIO	EXISTING MARSH	MARSH LOSS	OTHER LOSS*	TOTAL LOSS	NEW MARSH	DEFICIT FROM 1989**
2020						
0.4	1059	431	22	454	609	450
0.5	1059	552	30	582	508	552
2050						
0.8	1059	889	44	933	245	815
1.5	1059	1059	290	1349	10	1050
2100						
1.4	1059	1059	333	1393	0	1059
1.7	1059	1059	366	1426	0	1059
3	1059	1059	672	1732	70	990
4.4	1059	1059	1404	2463	700	359

* OTHER LOSS is uplands and sandy shorelines.
** DEFICIT FROM 1989 = existing marsh - new marsh.

It was observed that because of the topography of the study area, new marshes could be formed if sea level were to rise up to 1.4 feet. Between 431 and 552 acres of existing wetlands could be lost by the year 2020 (40 to 50 percent), for 0.4 and 0.5 feet sea level rise scenarios, respectively. Between 508 and 609 acres of marshes could be formed or survived by the year 2020, creating a deficit of 450 to 552 acres (40 to 50 percent) from existing wetlands. By the year 2050, sea level rise could cause the destruction of almost all existing marshes (889 and 1059 acres or 84 to 100 percent) for the two sea level rise scenarios, 0.8 and 1.5 feet. Under these sea level rise scenarios only a small amount of land would be available for marsh formation (245 acres for sea level rise of 0.8 feet). For the 1.5 feet sea level rise scenario, all marshes would be destroyed and no new land would be available for new marshes to form.

The situation could become even more drastic by the year 2100 with respect to existing marshes. All existing marshes will be affected by sea level rise by the year 2100. For sea level rise scenarios of 3 feet or higher some dry land areas could become flooded (in general, the topography of the study area becomes flatter above the 4 feet contour). We estimated that between 70 and 700 acres of land (3 and 4.4 feet scenarios, respectively) could be available for the formation of new wetlands. This still leaves a enormous deficit, between 93 and 32 percent, from existing wetlands. All of these estimates assume existing levels of development, and that no action is taken to mitigate or preserve wetlands.

The model projects that the wetlands of Zone 1 (Figure 3) would be most affected by sea level rise. For the year 2020, between 40 and 60 percent of the existing marshes could be destroyed (47 to 65 acres). When we compare these losses with the possible formation of new marshes, this area has the greatest deficits, between 63 and 75 percent by the year 2020. Moreover, the model did not project the formation of any new marshes for the highest sea level rise scenario. On the other hand, extensive new marshes could be formed on the north bank of the St. Martin River, Isle of Wight and the shores of Assawoman Bay for the highest sea level rise scenarios.

IV. 100-YEAR FLOOD

The National Flood Insurance Program (NFIP) of FEMA generates Flood Insurance Rate Maps (FIRM) to delineate areas subject to various degrees of flooding. We examined the impact of sea level rise on the 100-year flood zone (A-Zone) in our study area. The A-zone delineates an area that has a one percent chance of being flooded any given year. According to the FIRM's, the A-zone incorporates all areas between sea level and 6 feet above sea level in our study area. The exception occurs in Zone 1 (the shores of Isle of Wight Bay) where the A-Zone boundary varies between 6 and 8 feet above sea level.

We added the present A-zone boundary elevation with the various sea level rise scenarios to obtain hypothetical A-zone boundaries. The entire shoreline of the study area lies within the A-zone boundary. As sea level rises the probability for flooding along the shoreline and in previously unaffected upland areas will increase. As a result, human and natural resources will become under increasing pressure from flooding and its associated affects. The NFIP should revise their FIRMS as sea level rises because more residential, commercial and industrial structures will be affected by flooding (FEMA, 1991). These new areas would then be required to satisfy building codes for structures in A-zone boundaries (i.e., raise their structures).

SUMMARY

- 60 to 70 percent of the land at risk in our study area is classified as Suburban Residential land use.

- Most of the developed areas lie below the 5-foot contour.

- About 50 percent of the Isle of Wight is at risk of being eroded or permanently inundated for 4.4 feet of sea level rise.

- No major agricultural land would be at risk of erosion and inundation.

- The economy of the county would be affected by sea level rise because degradation of coastal resources and their associated benefits is probable.

- The analysis shows that all the existing wetlands in the study area (about 1500 acres) could disappear completely with sea level rise scenarios of 1.4 feet or greater.

- For sea level rise scenarios between 1.4 and 3 feet, marsh migration to upland areas is not possible or feasible. This is due to the presence of steep slopes between the 1 and 3 foot contours.

- For sea level rise scenarios of 3 and 4.4 feet, wetland migration to upland areas is possible because the topography of the study area at this elevation is gentler. We predict that between 70 and 700 acres of wetlands could form as a result of this scenario.

- The wetlands of Zone 1 will experience the most losses due to sea level rise because of their low elevation and because there exists many restrictions to their possible upland migration (i.e., steep slopes and development).

- The north bank of the St. Martin River, Isle of Wight and the shores of Assawoman Bay are the areas where most of the wetland migration to upland areas is possible.

CHAPTER SIX
STRATEGIES FOR MANAGEMENT

As land for development in the barrier islands of Maryland becomes scarce, the shores of the back bays will become increasingly attractive for new development. These lands are extremely vulnerable to any acceleration of sea level and its associated effect of increased erosion, inundation, flooding and saltwater intrusion. From an economic, safety and environmental point of view, we believe that strategies that diminish the possible damages and losses due to sea level rise must be established. These strategies can be propagated by the state's coastal zone management program.

Coastal zone management does not necessarily require restrictions on coastal development. It recognizes that coastal zones are attractive areas for development, but that a comprehensive plan to preserve natural resources and to allow certain forms of development is possible. The main objective of coastal zone management is to direct development to areas least susceptible to natural hazards. To do this effectively, it is necessary to incorporate sound scientific knowledge into development strategies.

A management plan for the coastal zone should take into account future sea level rise. It is essential that all parties involved in coastal development be active participants in the decision-making process. After scientific studies identify a potential problem, all of the affected parties should be educated about the results and possible strategies to mitigate any problems. Participants should include developers, environmental advocates, public officials, scientists and other citizen groups. Strategies that are made with formal and informal public participation have greater public acceptance and political support.

The issue of sea level rise has been widely publicized in the last couple of years. Despite this publicity many people do not know about the causes, mechanisms and consequences of sea level rise. Public education, at the national and state level, through media coverage, brochures, and meetings can improve peoples understanding and acceptance of the issues and the means to mitigate any problems.

It is important to recognize that any attempt to make coastal zone management more effective is labor intensive. The most serious impacts of sea level rise in the back bays of Maryland would be experienced under the higher sea level rise scenarios. These are projected to occur in the middle of the next century. This gives coastal communities some time to implement effective strategies. Coastal zone management plans can evolve with time. This does not mean that we should not start the planning process today. Coastal resources are undergoing serious degradation. **Coastal zone management may enhance the chances of preserving natural resources in the coastal zone, regardless of the accuracy of predictions regarding accelerated sea level rise.**

Planning for the future needs to start today, and public education is a good first step.

Coastal zone management plans must remain flexible as new scientific knowledge is attained. Scientific research in matters related to future sea level rise, such as magnitude and timing of occurrence, is critical. Equally important, but sometimes overlooked, is the need for applied research to determine which options are warranted, given current information. Finally, other climate change impacts, such as precipitation changes in coastal watersheds and changes in storm frequency and intensity should also be examined.

The principal objectives of coastal zone management in relationship to future sea level rise are to:

1) Avoid development in areas that are vulnerable to inundation and erosion;

2) Ensure that critical natural systems continue to function; and

3) Protect human lives, essential properties and economic activities from the sea.

We discuss three strategies available for coastal zone management to reduce the impacts of sea level rise: retreat, accommodation, and protection (IPCC Working Group III, 1990). In our study area the implementation of these strategies should be made on a site-specific manner. The retreat option or strategy involves no effort to protect the land from the sea. The accommodation strategy includes elevating buildings on piles or allowing arable land to become rougher pasture, etc. The protection strategy involves the placement of hard structures such as bulkheads and dikes, or soft solutions such as beach nourishment or artificial wetlands which protect existing land uses.

I. RETREAT

As sea level rises, coastal communities can abandon the area (or shore) and allow the sea to advance unobstructed. Existing development could be relocated inland. In addition, development setback standards could be established to reduce future development in hazardous areas. Although under this strategy the economic use of the land will be lost, it would prevent human and economic losses in the future. From an environmental point of view, a retreat strategy may increase the survival ability of wetlands.

Unfortunately, politicians will probably find the retreat strategy to be politically unfavorable. It is unrealistic to expect residents of coastal areas such as Ocean Pines or Cape of Isle of Wight to abandon their homes because of the possibility of future sea level rise. Three different approaches can be implemented to introduce a retreat strategy on existing development: (a) **restrict reconstruction of buildings and protective devices** after major storms and as sea level rises; (b) **presumed mobility** (Titus, 1991); and (c) **remove subsidies or increase incentives to guide development away from the coast.**

Several states have already implemented restrictions on rebuilding existing buildings and shoreline protection structures after they have been damaged from storms. In some cases, if a structure is more than 50 percent damaged, it cannot be rebuilt. As sea level rises, damage to most buildings in the coastal zone will increase.

Titus (1990) introduced the idea of presumed mobility. It involves incorporating sea level rise into the deeds of coastal property, and thus to the market economy. Presumed mobility does not interfere with the property rights of coastal home owners. Rather, it's similar to a long-term lease which for example, would expire after 99 years, or whenever the sea rises enough to inundate a property. As existing properties are sold and transferred the deed would still remain in effect.

The third approach is to provide direct financial incentive (i.e., tax reduction) for property owners to remove or relocate structures that are in highly hazardous areas or are in danger of imminent collapse due to erosion or flooding.

Retreat strategies for new development could include an array of policy alternatives (Klarin et al., 1990). The aim of these alternatives is to preserve existing wetlands and open spaces to allow wetlands to migrate to upland areas as sea level rises. We have found that in our study area there are limited areas where wetlands could form by migration to upland areas.

Setbacks either fixed or dynamic can be established to provide a buffer zone around wetlands. They should be established from the wetland/upland interface and not from the shoreline to account for seasonal and episodic variation in the spatial extent of the wetlands (Figure 48). **Conditional use permits** could be established to allow some temporary or restricted use of the land adjacent to wetlands. **Special zoning** regulations could be established to restrict structures or reduce their size and density within the coastal zone. **Environmental Impact Assessments** can incorporate potential sea level rise for proposed projects that would border wetlands and may lead to policies to protect them. Finally, reduce funding for infrastructure and other services that promote and direct new development in coastal zones.

We recommend that Worcester County investigates the utility of the strategies discussed above in order to reduce possible losses to human and natural resources due to sea level rise. According to the Worcester County Comprehensive Development Plan, Zones 1, 2, 3, 4, the lower areas of 5, and 9 (Figure 3) are those areas where development will most likely occur. Special attention should be directed to reducing coastal hazards at these areas and to plan for wetland migration to upland areas where possible. These areas include the north bank of the St. Martin River, the shores of Assawoman Bay and both banks at the mouth of Herring Creek (Figure 3).

II. ACCOMMODATION

The accommodation strategy assumes that occupation of vulnerable coastal areas will continue even under the risk of increased flooding and erosion due to sea level rise. Physically raising buildings is one of the most commonly suggested accommodation strategies. The National Flood Insurance Program's building standards attempt a similar strategy in flood prone areas. The life span of the structure is estimated and the height of the piling, for example, is calculated. The height of the base of the structures, estimated by the NFIP should include the 100-year flood level plus any projected future sea level rise values. The addition of 1 or 2 feet to the height of a support piling might save the structure in the future without adding much to the initial capital investment required to build the structure.

Open spaces where wetland migration is possible should be preserved. In areas with steep slopes, development could be allowed, while gentle sloping areas could be preserved for future wetland migration.

III. PROTECTION

Under the protection strategy, valuable real estate and existing structures are not abandoned as water levels rise. Most of the existing development areas along the shores in our study area will need protection. **However, as sea level rises, protection measures are just a temporary solution.** At one point in the future, protection will become either too costly or technically impossible.

Hard structures such as bulkheads are commonly used on the bay shores of Maryland. Some of the major environmental concerns and problems resulting from the construction of such structures are: (1) coastal marsh and other vital habitat areas are lost, (2) interruption of sand supply to adjacent shorelines. The adverse impacts are greatest when the outer periphery of a coastal marsh is bulkheaded in order to extend property lines and to provide boat landings.

Permits for the construction of new bulkheads should be closely regulated (Clark, 1983). A primary rule is that bulkheads in general should be discouraged in all cases, primarily where wetlands exist. Whenever possible, the existing shoreline should be preserved with natural protection measures such as marsh grasses. Bulkheads should be located landward of annual flooding, which marks the upland limit of the coastal wetland (Figure 49). They should be constructed so they do not disrupt the outward flow of ground water or runoff. This could be accomplished by constructing perforations ("seepholes" backed with screens) along the structure.

Figure 48. Comparison of setbacks: new development (center) setback from the shore, maintaining existing wetlands in contrast to older development (left) where wetlands where destroyed

Figure 49. Proper location of bulkheads: behind the line of annual flooding, which marks the inner edge of the coastal wetland.

Riprap is often an easier and a less costly technique for protection and it has a higher permeability than other methods.

A more desirable protection measure, which should be encouraged on the shores of the study area is the planting of wetland vegetation. This is the most effective method of preserving wetlands on these shores. Marsh planting is most useful where erosion rates and wave action are low. The artificial marsh has the benefit of creating a more biologically productive shoreline, as well as being aesthetically appealing. Methods for marsh creation and restoration are outlined in several papers (Woodhouse, 1979; Knutson and Woodhouse, 1983; Lewis, 1982; Zedler, 1984). Most marsh creation projects are only possible in the upper third of an intertidal area. Mechanical grading may be necessary to form a lower slope angle (this has the added advantage of offsetting the chances of destructive wave action by creating a more dissipative shoaling zone). It has been estimated that a minimum of 6 m (20 feet) of new planted marsh are needed for the success of a new marsh. Marsh vegetation may be propagated by seed or by transplants. Placing a temporary breakwater along the seaward margin may be recommended to diminish erosion or overwash.

Summary of Strategies

Retreat
Existing Development:
- Restrict reconstruction of buildings and protection.
- Presumed mobility
- Subsidies and incentives to relocate

New Development:
- Setbacks
- Conditional use permits
- Zoning
- Environmental reviews
- Mitigation

Accommodation
- Building code standards: rising buildings
- Open space requirements for new developments
- Land use change: changing crops to more salt tolerant ones

Protection
- Natural protection: planted marsh grasses
- Bulkheads behind the line of annual flooding
- Ripraps

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APPENDIX

REPRESENTATIVE PROFILES

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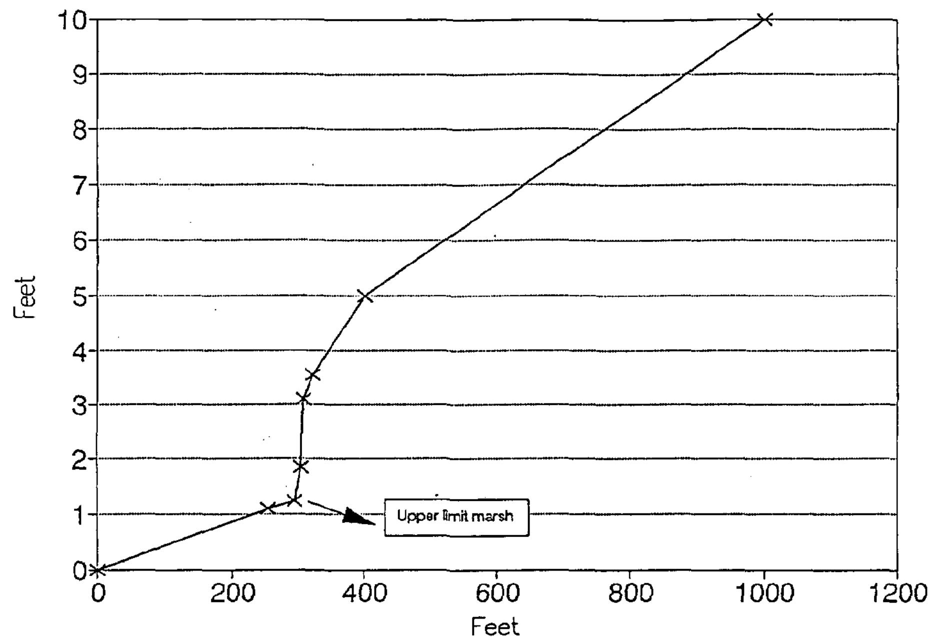

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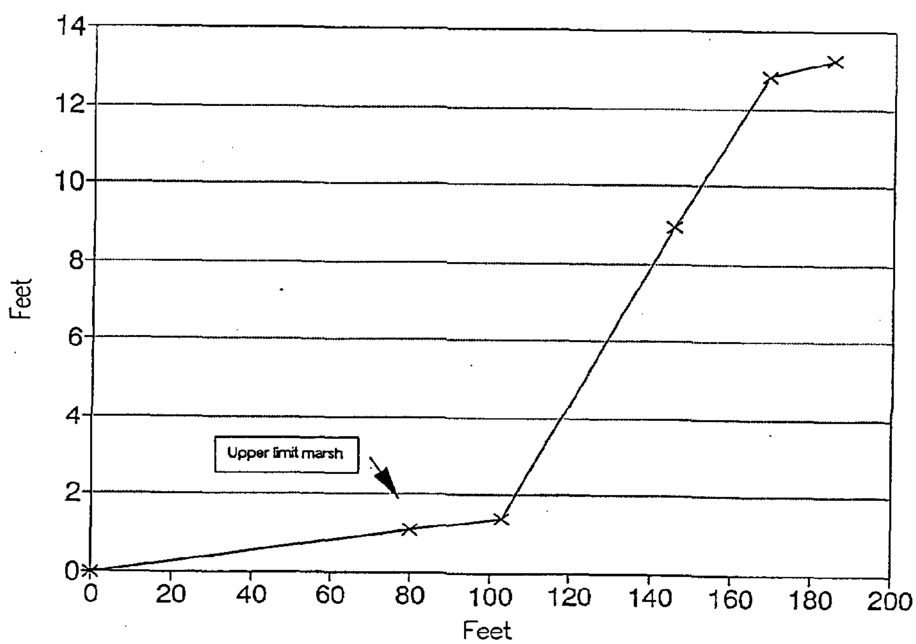

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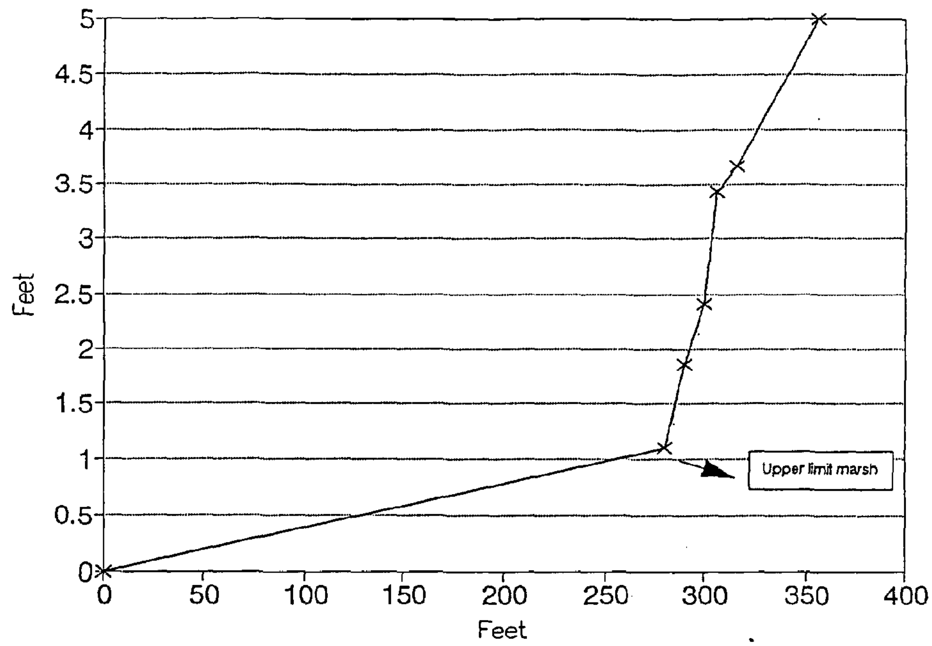

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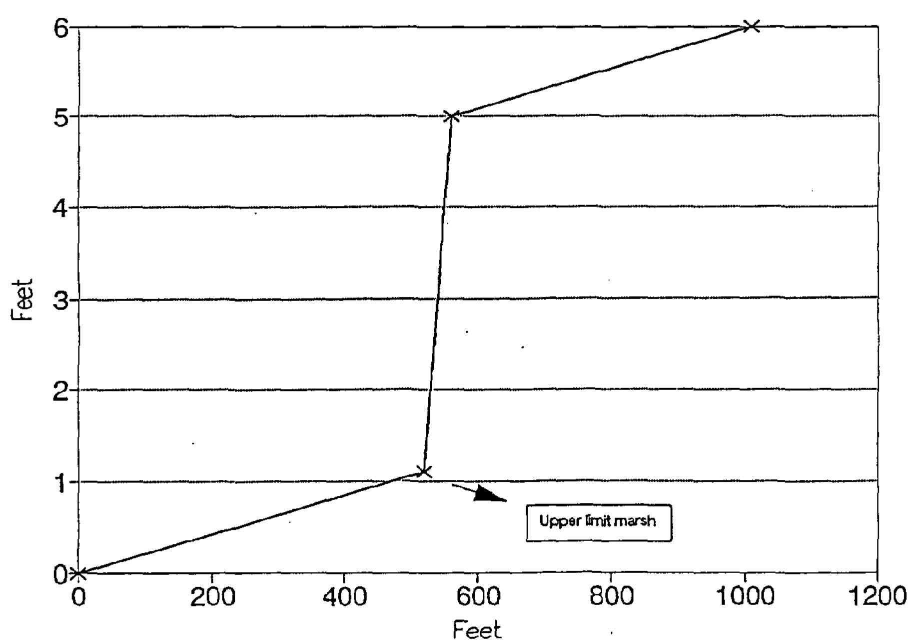

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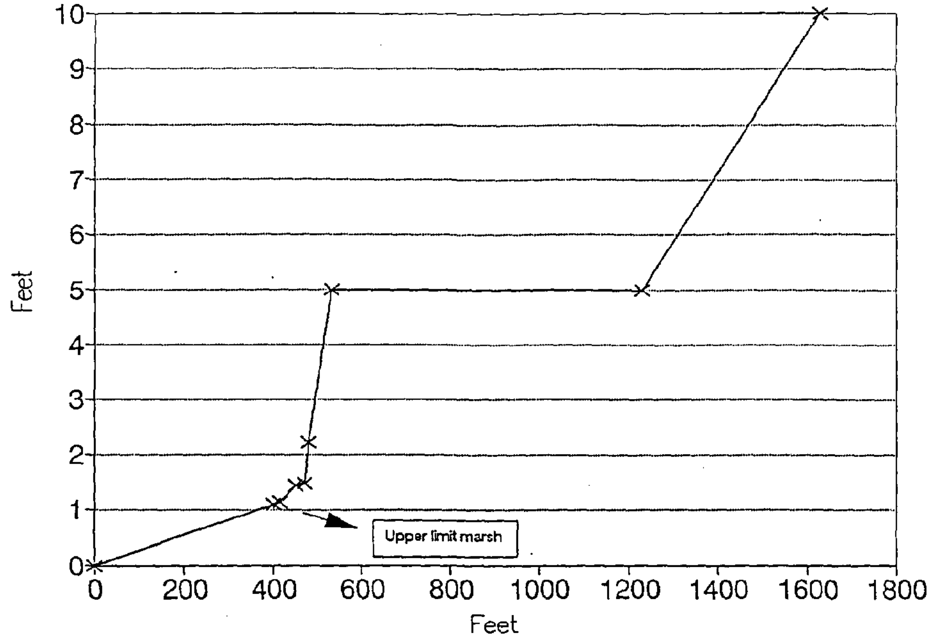

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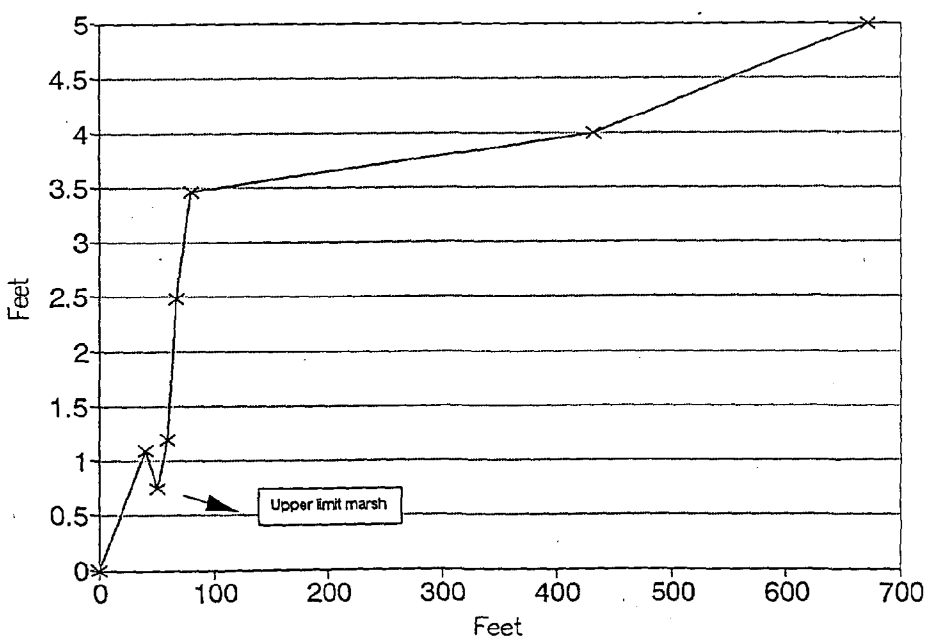

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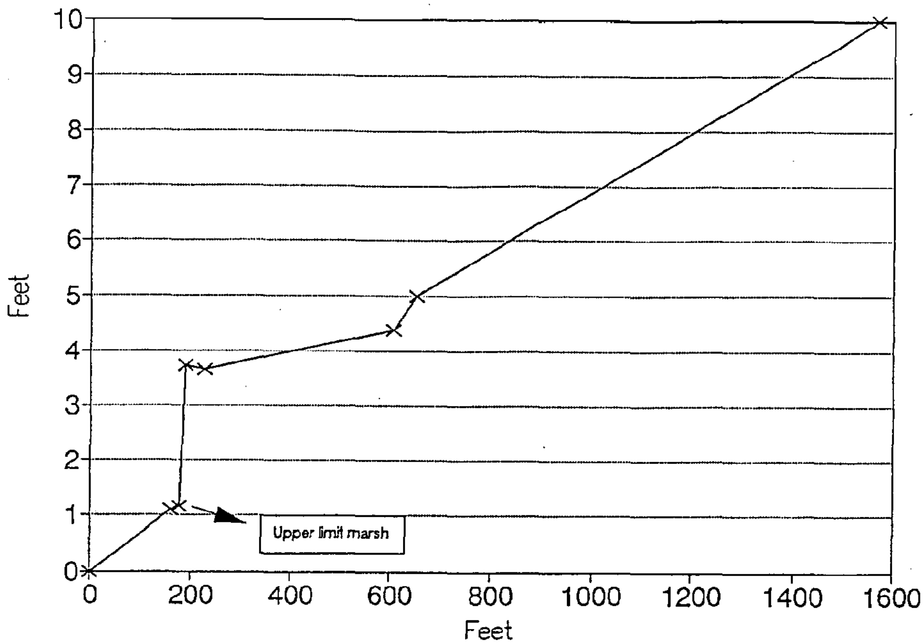

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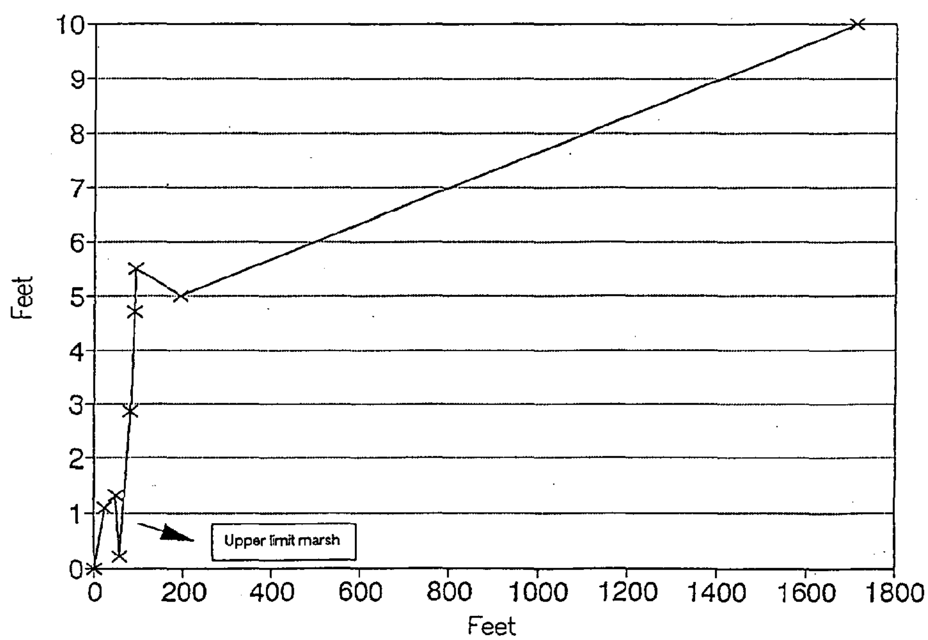

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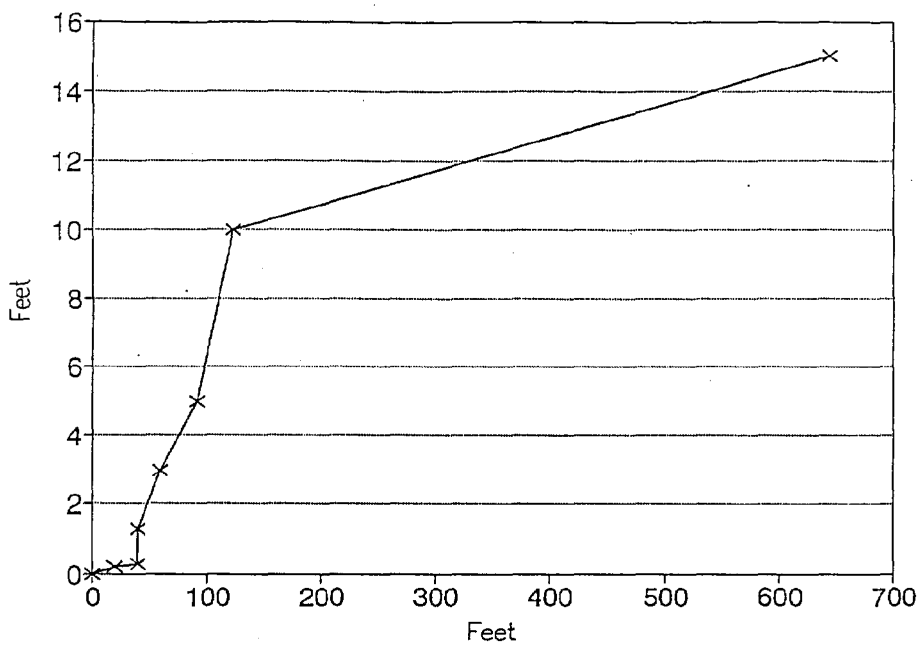

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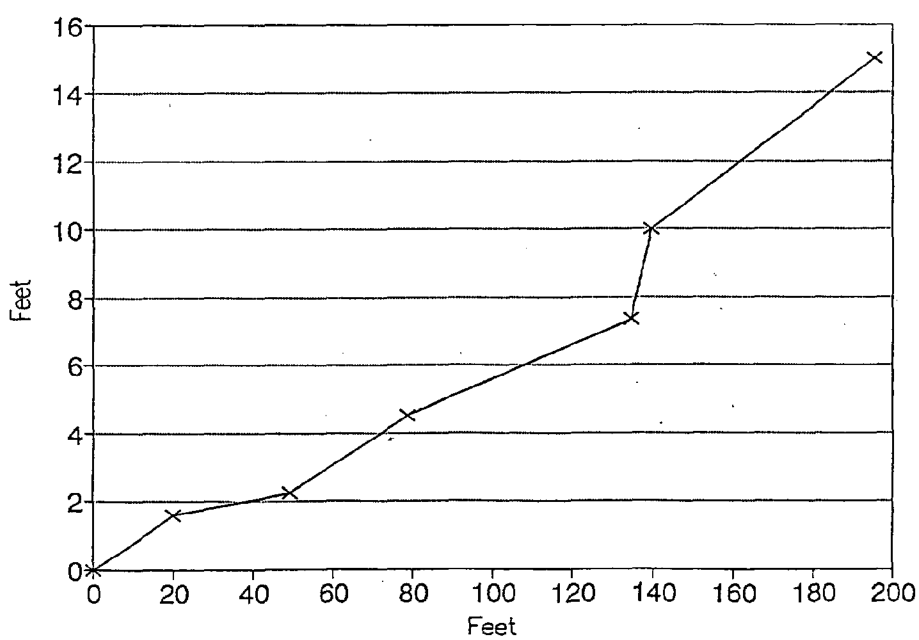

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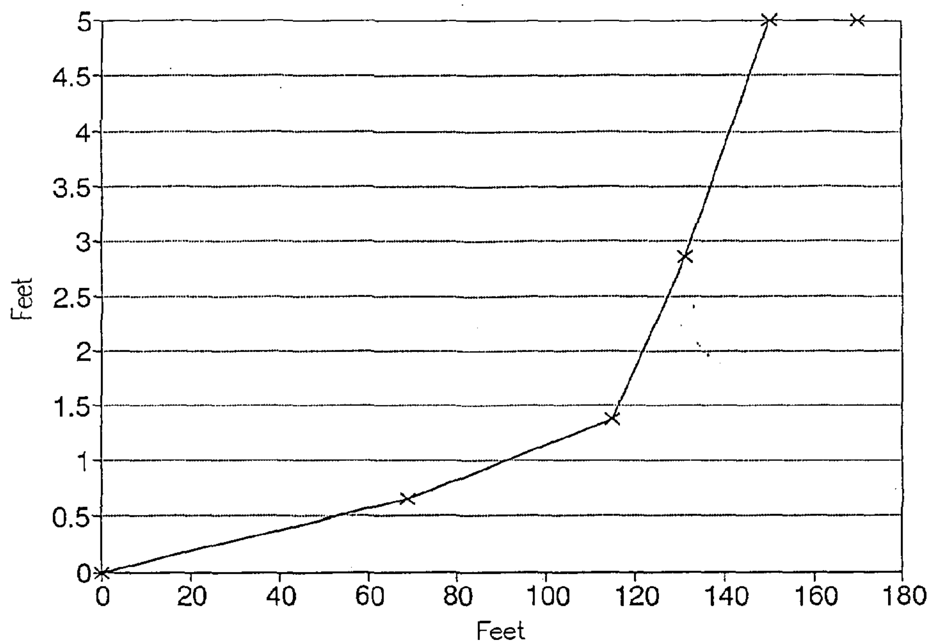

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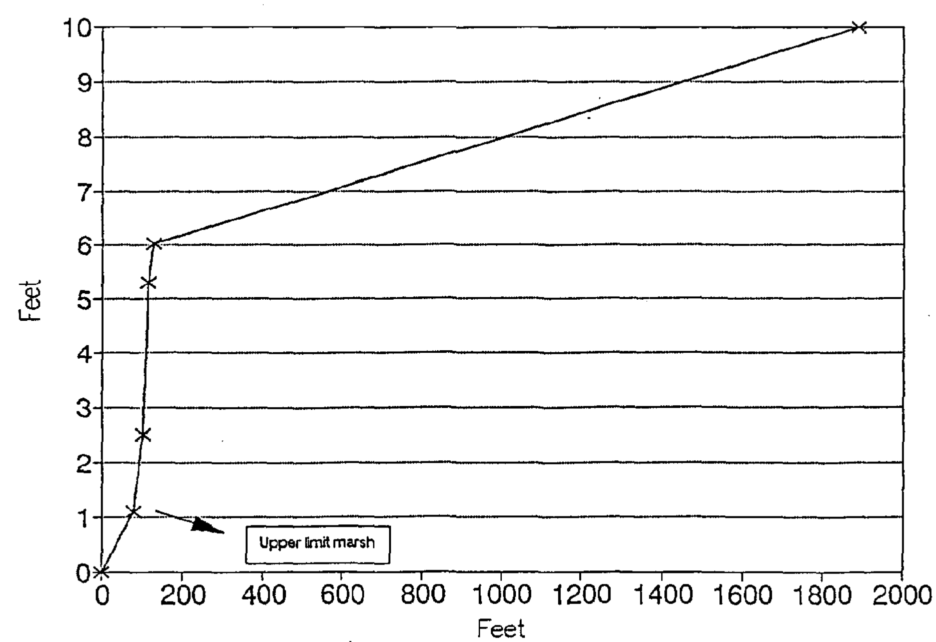

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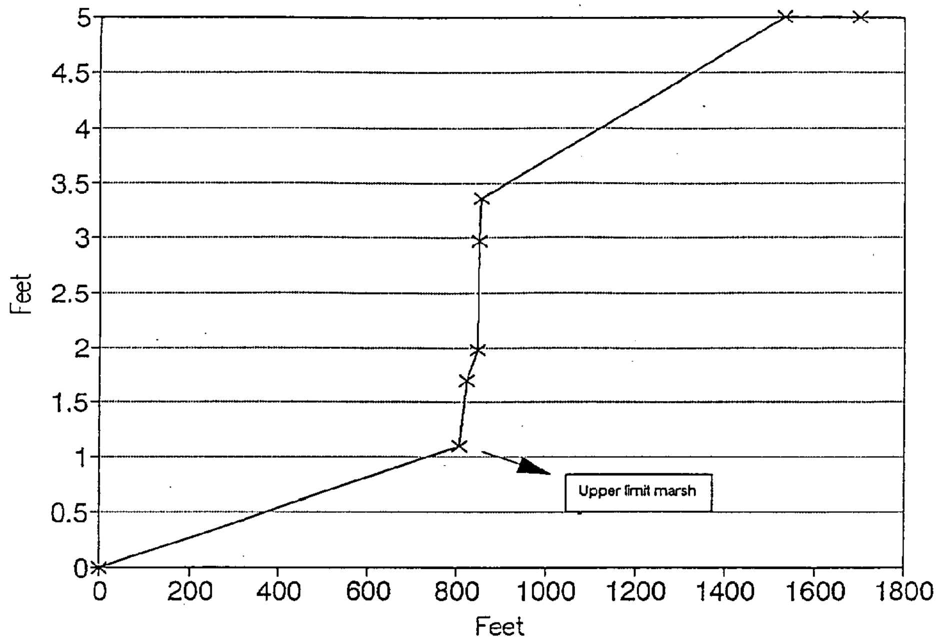
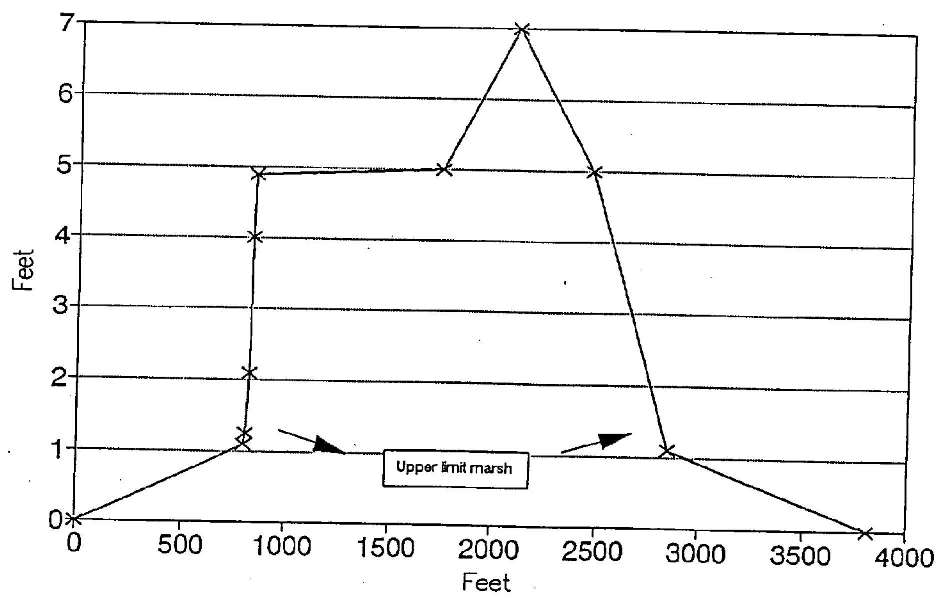


Site 41

St. Martin Neck Cross Section



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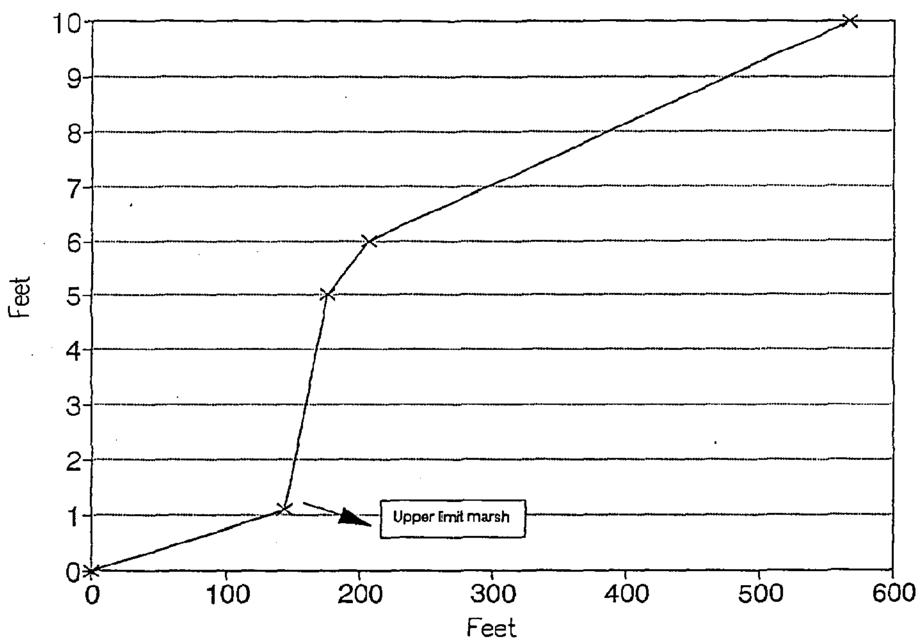

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